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A REVIEW OF THEORY AND EMPIRICAL RESEARCH ON "THE LEARNING BY DISCOVERY HYPOTHESIS," AND RELATED LITERATURE ON CONCEPT-LEARNING AND PROBLEM-SOLVING, WAS PREPARED FOR A CONFERENCE IN NEW YORK CITY, 1965. RECENT CURRICULAR ACTIVITIES IN THE SUBJECT AREA WERE DESCRIBED. ATTEMPTS WERE MADE TO IDENTIFY INDEPENDENT AND DEPENDENT VARIABLES AND THE EXTENT OF RESEARCH IN THE SUBJECT AREA, AND TO DESCRIBE RELATED RESEARCH ON CONCEPT-LEARNING, PROBLEM-SOLVING, AND TRANSFER. RESULTS FROM THESE EFFORTS WERE DISCUSSED, AND SOME IMPLICATIONS FOR FURTHER RESEARCH ON LEARNING BY DISCOVERY WERE PRESENTED. (JM)

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The Learning by Discovery Hypothesis

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I. Introduction

Seated at a desk in his school, a child tries to solve a problem in mathematics. First he tries one hypothesis, then another--both fail. A third hypothesis brings the correct answer to the problem. He knows the answer is correct just as he knew the first two attempts were incorrect. The answer is not arbitrary and need not be confirmed by a teacher. Here is one example of what is meant by "learning by discovery". As a description and conceptualization of a type of human learning, how useful a model is it? Is it a conceptualization useful for the design of classroom instruction?

According to some of its proponents, learning by discovery produces knowledge which transfers to new situations. It provides practice at learning to solve problems and therefore develops problem solving ability. It is intrinsically motivating and is its own reward. It helps to make a student a more mature person by teaching him to solve problems, to behave in a scientific and inductive fashion, and to go beyond the data. It is a useful model for the teaching of many subjects in schools. Left to his own resources the student's individual history will determine the proper sequence of learning activities. In any event it is an importnat end in its own right. It deserves attention, and students should have some practice at discovering answers for themselves. One must learn to produce rather than to reproduce answers and knowledge.

According to others who are less enthusiastic about it, only those students who have already learned how to discover may learn by discovery. It confuses means with ends and it depreciates the importance of the history of the subject.

To produce ability to discover (an end) may involve more than simple practice at discovering (a means). Discovery is time consuming. The essence of a culture is that everyone need not discover for himself everything anew, but that he can profit from the experiences of others as summarized in verbal form. Even the motivation it produces may be to escape and later to avoid the subject matter, because the problems threaten rather than challenge the student's intellect and self-concept.

As an end, ability to solve problems is important, but it is not the only important end. One must learn to acquire and comprehend much of his culture as well as to discover new knowledge and to solve problems.

So goes the opposition to learning by discovery.

The primary purpose of this paper is to review some of the thought and empirical research on the learning by discovery hypothesis and to relate this thought and empirical research to some of the literature on concept learning and problem solving. Although the studies on learning by discovery have been discussed or reviewed before (e.g. Ausubel, 1963; Cronbach, 1963; and Kersh and Wittrock, 1962) there has been little attempt to relate these studies to the empirical research on problem solving and concept learning.

This paper is organized into six major parts. The first part is the Introduction. The second part presents the learning by discovery hypothesis including some of its historical roots. Third is a brief description of some of the recent curricular movements which have involved learning by discovery in their programs. The fourth major section reviews a representative sample of research on learning by discovery and also tries to identify some of the independent and dependent variables which are extant in the research. The fifth section samples research on concept learning, problem solving, and transfer with the hope that this research will transfer positively to variables which are characteristic of research on learning by discovery. The sixth section discusses the results from these different areas of research and presents some implications for further research on learning by discovery. Special attention is given to the recent work on learning of hierarchically arranged subject matter which appears to be indicating a productive approach for future research. A definition of the term "learning by discovery" is also attempted in this final section. The reason for defining the term in the final section, rather than defining it earlier, will be apparent after the reader has encountered some of its many uses.

II. The Hypothesis

Current Interest

There are definite ideas among writers on human learning and education about the sequence and arrangement of verbal and non-verbal stimuli which should or should not be presented to students to produce transfer, savings, ability to discover, and intense, "intrinsic" motivation and self-confidence. To present some of this excitement and some flavor which accompanies the learning by discovery hypothesis, several lengthy quotes are presented below. These quotes help to convey accurately some of the reasons for teaching and learning by discovery.

Suchman (undated) states many of the advantages which are claimed for teaching by discovery and for learning by discovery. Speaking about a program to improve inquiry skills he writes, (Pp. 6-7)

The need for improvement is great. Current educational practice tends to make children less autonomous and less empirical in their search for understanding as they move up the elementary grades. The schools must have a new pedagogy with a new set of goals which subordinate retention to thinking.

It is clear that such a program should offer large amounts of practice in exploring, manipulating and searching. The children should be given a maximum of opportunity to experience autonomous discovery. New goals must be set for children. Instead of devoting their efforts to storing information and recalling it on demand, they would be developing the cognitive functions needed to seek out and organize information in a way that would be the most productive of new concepts. Both the teacher and the pupil would have to be cast in new roles. The pupil must become more active and aggressive in his learning role. Direction of the concept formation process should be his own, and he should come to regard his environment (including the teacher) as a potential source of information which can be obtained through his own acts of inquiry. The teacher must abandon his traditionally directive mode and structure an environment that is responsive to the child's quest for information. The teacher must see to it that the child's efforts at inquiry are rewarded by success, that the child is able to obtain the information he needs and that he does discover new concepts on his own. The teacher can help the child by posing problems that are reasonably structured and will lead to exciting new discoveries. The teacher can also coach him in the techniques of data collection and organization that will lend power and control to his searching. The educator should be concerned above all with the child's process of thinking, trusting that the growth of content will follow in the wake of inquiry.

For the past four years, we have been attempting to design and test just such a program to be employed in the elementary school. The following section describes our method, which we call Inquiry Training.

He then describes demonstrations in physics, designed for intermediate grade children. The children are asked to discover why a demonstration had the results it did. The verbal behavior of children is restricted to operating inductively with data gathering questions. They cannot ask the teacher if their hypotheses are valid.

The teacher provides not the final word on the validity of propositions; he merely supplies the necessary responses that permit the child to perform verbal experiments of his own design. The child decides which variables he will explore. He structures

> his own independent variables and predicts their effects on the dependent variables of concern to him. He asks the teacher whether his predicted results would, in fact, occur. The teacher merely answers "yes" or "no" (or indicates that the experiment was not well enough controlled for an unequivocal answer). The child must interpret this answer and continue with his experiments until he has discovered the relationships he is searching for. (Suchman, undated, P. 9).

One of the most eloquent descriptions of the transfer which learning by discovery produces in the student comes from Bruner (1959, P. 184).

> Learning something in a generic way is like leaping over a barrier. On the other side of the barrier is thinking. When the generic has been grasped, it is then that we are able to recognize the new problems we encounter as exemplars of old principles we have mastered. Once over the barrier, we are able to benefit from what William James long ago called "the electric sense of analogy".

After commenting on the passivity of knowledge-getting in the classroom (peaches are grown in Georgia--New York is our largest port, etc.) which lacks thinking as a reward for learning, Bruner writes, (1959, Pp. 187-88)

> One experiment which I can report provides encouragement. It was devised and carried out by the research group with which I am associated at Harvard in collaboration with teachings in the fifth grade of a good public school. It is on the unpromising topic of the geography of the North Central States and is currently in progress so that I cannot give all of the results. We hit upon the happy idea of presenting this chunk of geography not as a set of knowns, but as a set of unknowns. One class was presented blank maps, containing only tracings of the rivers and lakes of the area as well as the natural resources. They were asked as a first exercise to indicate where the principal cities would be located, where the railroads, and where the main highways. Books and maps were not permitted and "looking up the facts" was cast in sinful light. Upon completing this exercise, a class discussion was begun in which the children attempted to justify why the major city would be here, a large city there, a railroad on this line, etc.
>
> The discussion was a hot one. After an hour, and much pleading, permission was given to consult the rolled up wall map. I will never forget one young student as he pointed his finger at the foot of Lake Michigan, shouting "Yipee, Chicago is at the end of the pointing-down lake". And another replying, "Well, OK; but Chicago's no good for the rivers and it should be here where there is a big city (St. Louis)." These children were thinking, and learn-

> ing was an instrument for checking and improving the process. To at least a half dozen children in the class it is not a matter of indifference that no big city is to be found at the junction of Lake Huron, Lake Michigan, and Lake Ontairo. They were slightly shaken up transportation theorists when the facts were in.
>
> The children in another class taught conventionally, got their facts all right, sitting down, benchbound. And that was that. We will see in six months which group remembers more. But whichever does, one thing I will predict. One group learned geography as a set of rational acts of induction-that cities spring up where there is water, where there are natural resources, where there are things to be processed and shipped. The other group learned passively that there were arbitrary sources of supply. One learned geography as a form of activity. The other stored some names and positions as a passive form of registration.

In another well known article (1961) Bruner discusses four benefits which are said to accrue from discovery learning. They are greater intellectual potency, intrinsic motivation, memory processing, and the learning of the heuristics of discovery. Concluding the section on intellectual potency (P. 27) he presents the learning by discovery hypothesis.

> It is, if you will, a necessary condition for learning the variety of techniques of problem solving, of transforming information for better use, indeed for learning how to go about the very task of learning. Practice in discovering for oneself teaches one to acquire information in a way that makes that information more readily viable in problem solving. So goes the hypothesis. It is still in need of testing. But it is an hypothesis of such important human implications that we cannot afford not to test it--and testing will have to be in the schools.

Comment

It is important that children be taught to discover on their own, to be able to retain knowledge, to transfer to new but related situations, (including further study in the same discipline) and to be motivated to continue to learn, and increase in independence. However, these above quotes include not only ends but means. It is a particular way of learning which is hypothesized to produce these important ends.

After observing the children's overt behavior, Bruner concludes that the children presented with the blank maps were thinking. No doubt they were. But it would be better to have empirical data to index their thought. It seems that regardless of which group performs better six months after learning, the group that received the blank maps received the better treatment. Herein lies the crux of the dilemma among educational psychologists about discovery learning. It does no good to say that those who discover learn best when the learning and the discovery are measured by one event. The treatment is an independent variable which may or may not produce transfer, savings, or retention etc., as well as or better than some other treatment. As Bruner suggests, the hypotheses should be tested. To evaluate discovery learning we should obtain empirical data on the consequences it produces.

Earlier Interest

Before summarizing the empirical data on the hypothesis, a brief look at its historical roots is in order. J.J. Rousseau in his book Emile insisted that the proper role of the environment is to avoid interference with the internal processes of spontaneous maturation. Teacher direction, goals, and standards were to be replaced by a permissiveness which would allow the innately good child to realize himself best. Pestalozzi and Froebel shared some of the implications of Rousseau's non-directive and child centered approaches to learning.

Maria Montessori (1912 and 1917) pioneered an important movement in education. Montessori (1917) emphasized the freedom of the child and the child's choosing for himself the problems or subject matter he would attempt. The teacher neither gives little deliberate, verbal direction to the child, nor does she often reinforce the child with words, smiles, or other verbal or social reinforcers.

For example, children are taught form and sound discrimination by experimenting with apparatus which the Montessori teachers have evolved. The apparatus is designed to provide feedback to a child without the necessity of intervention of a teacher. In discussing how a child's senses are trained by having him insert objects into a form board, Montessori writes (1912, Pp. 171-172)

> Here instead is the work of the child, the auto-correction, the auto-education which acts, for the teacher must not interfere in the slightest way. No teacher can furnish the child with the agility which he acquires thrugh gymnastic exercises; it is necessary that the pupil perfect himself through his own efforts. It is very much the same with the education of the senses.
>
> It might be said that the same thing is true of every form of education. A man is not what he is because of the teachers he has had, but because of what he has done.

And in another volume (1917, P. 5) after giving examples of futile attempts of people to control the development of children's legs, noses, ears, head, and the development of their character and intelligence she writes,

> It is nature, "creation," which regulates all these things. If we are convinced of this, we must admit as a principle the necessity of "not introducing obstacles to natural development"; and instead of having to deal with many separate problems-such as, what are the best aids to the development of character, intelligence and feeling?- one single problem will present itself as the basis of all education: How are we to give the child freedom?"

Later, (1917, Pp. 67-68) she presents an episode which was important to her in the search for the discovery of a treatment required by the soul of the child which would be analogous to what hygiene prescribes for the body.

> I think, therefore, that it is essential to record the fundamental fact which led me to define my method.

> I was making my first essays in applying the principles and part of the material I had used for many years previously in the education of deficient children, to the normal children of the San Lorenzo quarter in Rome, when I happened to notice a little girl of about three years old deeply absorbed in a set of solid insets, removing the wooden cylinders from their respective holes and replacing them. The expression on the child's face was one of such concentrated attention that it seemed to me an extraordinary manifestation; up to this time none of the children had ever shown such fixity of interest in an object; and my belief in the characteristic instability of attention in young children, who flit incessantly from one thing to another, made me peculiarly alive to the phenomenon.
>
> I watched the child intently without disturbing her at first, and began to count now many times she repeated the exercise; then, seeing that she was continuing for a long time, I picked up the little arm-chair in which she was seated, and placed chair and child upon the table; the little creature hastily caught up her case of insets, laid it across the arms of her chair, and gathering the cylinders into her lap, set to work again. Then I called upon all the children to sing; they sang, but the little girl continued undisturbed, repeating her exercise even after the short song had come to an end. I counted forty-four repetitions; when at last she ceased, it was quite independently of any surrounding stimuli which might have distracted her, and she looked round with a satisfied air, almost as if awaking from a refreshing nap.
>
> I think my never-to-be-forgotten impression was that experienced by one who has made a discovery.

With her willingness first to observe children's behavior and then to induce from these observations innovations which might affect learning, she has contributed much to educational practice and thought. She was also willing to introduce innovations into the classroom. Unfortunately, she was less interested in the difficult problems of measuring the results of these innovations.

In quite a different way, John Dewey's (1910) preferences for problem solving, laboatory work and the "scientific method" produced a decided effect upon education in our own century. In place of stultifying drill, and an excessive amount of memorization that characterized faculty psychology as well as the schools of the late 1800's and the early 1900's, he suggested concrete experience, active responses, problem-solving projects, and "do-it-yourself" learning.

The first phase of the curriculum was structured in terms of the interests of the child. The teacher attempted to help each child achieve meaning free of much verbal direction.

What had begun as an improvement upon the somewhat sterile, formal education of 1900, became itself a problem to be solved. The teacher who surrounded herself with art objects from Africa one morning and then said to the class "What shall we talk about today?" is directing children although she may not be aware of it.

Although he emphasized social interaction and problem solving as ways to learn, he also recognized three levels to the curriculum. The third level presented subject matter organized according to the structure of the discipline and not necessarily in terms of the student's own needs or problems.

Until experimental data are available, it will be difficult to isolate the independent variables in the above types of demonstration schools. Such factors as the Hawthorne effect, highly selected children, and novelty will have to be controlled before definitive statements can be made.

Comment

From the above quotes and discussion, it is clear that learning by discovery is both an end and a means for some educational theorists. By discovery a student is supposed to learn regularities and concepts within a discipline. But more importantly he is supposed to learn how to solve problems, to go beyond the data, to behave as a junior scientist. He is supposed to become motivated and enthusiastic about the discipline. He is to know personal satisfaction because he has selected his own sequence of problems and, through active responses of his own, has succeeded at these problems. Seductive as these propositions appear on the surface, they are complicated.

III. Samples of the Curriculum Projects

UICSM

As early as 1952, the University of Illinois began to prepare materials and teachers to improve the teaching of secondary school mathematics. Max Beberman (1964, Pp. 9-34) describes some of the careful planning and organization of materials and some of the objectives of the program. He gives (Pp. 11 and 23) two operationally defined desiderata for the understanding of mathematics: 1) precision of textbook language and of teacher language and 2) student discovery of generalizations. (It seems that cause and effect may be somewhat confounded here. These desiderata of the dependent variables of meaning and understanding are also the independent variables--the treatments--which are supposed to produce the understanding of mathematics. For example, by practicing discovering, mathematics is supposed to be made meaningful. How do we know this? Because discovery has been practiced).

But more important than this use of terms is the impressive set of materials which the Committee (UICSM) has prepared. The Department of Mathematics, the College of Education, and the University High School cooperated in preparing, trying out and testing their materials. The terminal behavior of students who complete the program seems to indicate that some inportant improvements in the teaching of mathematics in the secondary school have been introduced.

SMSG

The UICSM is only one of many groups which are working on the improvement of the teaching of Mathematics. A national effort, rather than a state or local one, is presented by the School Mathematics Study Group (SMSG), which is financed by the National Science Foundation, and was begun in 1958. A brief history of SMSG is presented by William Wooten (1964, Pp. 35-53). The sample textbooks and other materials prepared by this group are characterized by a careful sequencing and structuring of basic mathematical concepts (e.g., numeration, number systems, and intuitive plane geometry in Grade 7) and also by involvement of the student in discovery of mathematical concepts. These materials have been enthusiastically received by many teachers, administrators, parents, and students. For review of other mathematics projects see Goodlad, (1964).

CHEM

The preference among scholars for teaching by discovery is not limited to mathematics. The Chemical Education Material Study, (CHEM), by 1963 produced a "new" course in Chemistry (Campbell, 1964, Pp. 82-93). With movies, text, and laboratory manual, a series of laboratory experiments was prepared. These experiments are designed to be encountered by the student before he studies the related material in the text. The student is to discover (P. 87) through laboratory experiments, the basic ideas of the course, including such fundamentals as kinetic theory and atomic structure. The discovery precedes the discussion of these concepts in the text, as the third major part of the text includes applications of these ideas.

One could name other relatively new and important curriculum projects, e.g., the American Institute of Biological Sciences (AIBS) project in the teaching of Biology. Many of these projects are also sympathetic to a "learning by discovery" procedure.

Comment

It is difficult to evaluate the many dimensions of change which these new projects and their courses produce in students. Although these projects are quite new, apparently for many students they present most important advances in teaching.

However, it is equally clear that the courses themselves involve many complicated dimensions in addition to those of careful sequencing and student discovery. The success of these programs does not, in any serious sense, support or refute the contention that learning by discovery is important for learning the subject matter, for learning a way of solving problems, or for that matter, important for any other educational objective.

So far as these curricular demonstrations are concerned, learning by discovery is still an hypothesis--an untested one at that. In the sense that learning by discovery involves student selection of the sequence of materials, it is not involved in these projects, which have a sequence very carefully designed by scholars and by schoolmen. In the sense that learning by discovery implies student encounters with problems and raw data and student derivation of concepts or principles, discovery is definitely involved in these curricular projects.

IV. A Review of the Empirical Research on the Hypothesis

Not all of the significant pieces of research on learning by discovery are included below. Instead, a representative sample, which includes many of the significant studies, is presented. Many of the older studies lack rigor both in the definition of the independent and dependent variables and in the methodology, including statistical analysis of results. However, the author has chosen not to dwell on these methodological problems. To do so would require a separate paper. Many of the more recent studies, and a few of the older ones, were carefully executed and analyzed. The hypothesis has received considerable attention among educational psychologists and curriculum and instruction specialists. The early research apparently began with an interest in comparing connectionism with field theory or a variant of field theory. Learning by discovery, as an issue in its own right, grew from this connectionist-field theory dilemma. The research on the discovery hypothesis can be divided into at least two areas or approaches. First is the research which was primarily interested in finding which independent variables would influence the dependent variables of transfer, retention and savings. This type of research is characterized by an attempt to label objectively the treatments and to produce functional relations between the treatments and the dependent variables, (e.g. Craig & Kittell).

A second area or approach continued to be interested primarily in theory and in discovery as an intervening variable. However, the theoretical issue became less of the original connectionism-field dichotomy and became more interested in why discovery was effective; e.g., Hendrix (1947) hypothesized a sub-verbal awareness and Kersh (1958 & 1962) hypothesized a motivation variable. Kersh's current interest leads him to endorse White's (1959) model on effectance and competence motivation. However, before discussing these current trends of interest in discovery learning, several earlier studies are presented to provide a proper setting.

Early Studies

One of the earliest and best known of empirical studies which can be called a study of learning by discovery is one by Judd (1908). He used transfer as a criterion and studied the teaching of a relationship between the depth of water and the refraction which results when one looks from a less dense medium (air) into a more dense medium (water) with an angle of incidence appropriate to produce a refraction. One group was taught, in verbal form, the principle of refraction. They then practiced throwing darts at a submerged target. Another group was given the same total instructional time, but the time was used to practice throwing darts without the teacher' s verbalization and explanation of the principle. On a transfer test in which the depth of the water was changed, the group given the preliminary verbal training performed the best. (Hendrickson and Schroeder, 1943, with different materials and apparatus studied this same effect). Although it is easy to criticize Judd' s apparatus, and technique, he asked a most important question which, as we shall see below, much other research supports.

In 1927 Judd wrote "The human power of generalization is so intimately related to the evolution of language that the two cannot be thought of as existing separately . . .language is the chief instrument of generalization. . ." (as quoted by Hendrix, 1961, P. 292).

Radossowljevitch (1907) emphasized the importance of verbal instruction upon learning a list of syllables. A subject with a language difficulty failed to understand the experimenter's directions. After 64 repetitions of a series of eight syllables presented on a memory drum, the subject still did not indicate that he had mastered the list. The subject had read aloud all eight syllables each of the 64 times they had been presented. When he was told that he was required to memorize the eight syllables, six additional trials were necessary before mastery was achieved by the subject. The importance of at least a minimal amount of direction upon learning of a rote nature was evidenced by Radossowljevitch.

Clark Hull (1920, Experiment G) compared the learning produced by coloring in red a common element, a written Chinese character, with the learning produced when the Ss were allowed to discover, without its appearing in red, the shape of the common element. He found the former, the more highly directed treatment, to be the better one of the two.

Thorndike's extensive research on the law of effect, including the relative effects upon learning of reward and punishment,has stimulated much research on discovery learning including not only on the reinforcement variables, but also the stimuli presented before a learner makes a response. There is quote from Thorndike which often appears in studies on discovery. "The attainment of active vs. passive learning at the cost of practice in error may often be a bad bargain . . .The almost universal tolerance of imperfect learning in the early treatment of a topic, leaving it to be improved by the gradual elimination of errors in the later treatments, is probably unsound and certainly risky." (1935, P. 147). These sentences, and others of his have been interpreted (e.g. Swenson, Anderson,

& Stacey, 1949) as an attempt to explain complex human learning in terms of simple learning and to deemphasize the arrangement of stimuli, the meaningfulness of material, the importance of discovery learning.

One result of these writings and later interpretations of them was experimentation on connectionism vs. generalization or meaning theory. Something other than a test of discovery was imbedded in this theoretical controversy. Judd and later Katona (1940) verbalized the generalizations or the principles which were important to the subjects to solve the dart throwing or the card trick problems. In Katona's studies, the best performance at solving the card-trick problems was achieved by those who listened to an explanation of a basic problem and then matched a carefully directed, step-by-step demonstration by E. That procedure was better than learning a verbally stated principle without exploration, which in turn was better than memorizing steps to the solution.

Recent Studies on the Hypothesis

The studies presented in this section are difficult to organize because they differ among one another on many dimensions: theory,objectives, methodological rigor, age of learners, labels for the treatments, variety of treatments, and measures of the dependent variables. But there are two dimensions which are helpful for understanding the relationships that exist among these studies. The first one is chronology because the issues become clearer as the earlier work leads to new variables and to new approaches. The second was mentioned earlier, and consists of a change in the complex of theory about and conceptualization about the independent, intervening, and dependent variables which are important in learning by discovery. More specifically, there is a progression from prediction to results on the bases of hypothetical covert behavior of the subject to prediction based on the stimuli and their functional relationships to covert responses and to the measurable overt responses. Earlier there seems to be little doubt that certain treatments (e.g. rote treatments) inevitably will produce little transfer or "understanding". Later there is among one group of studies much concern for separating the independent variables from the dependent variables and for measuring what is meant by discovery. Is it remote transfer, savings, etc. or is it an intervening event which is indexed by transfer and savings tests? In brief, the meaning and connectionism issue, which was important in stimulating the early research, becomes translated into a discovery vs. direction issue, which in turn, becomes somewhat operational. As operational definitions increase, several issues and dimensions arise to replace the original and oversimplified one. The research becomes more and more complex, the terms less emotional, the variables greater in number, and the results more confusing at times and more useful at other times. This is not to say that these later studies were invariably more clearly conceptualized and executed. Only that there is a general trend toward clarifying the issues and the dimensions. Unfortunately, some of these later studies tend to err in the direction of too little conceptualization and theory. The other noticeable trend tends to refine the intervening variables but tends to be less concerned with refinement in the independent and dependent variables. The studies below are grouped primarily by chronology with frequent reference to the distinction mentioned in the sentence immediately above.

It is not possible to provide a highly detailed summary of each study.

Instead several studies are explained in depth to represent types of experimental approach and their results. The other studies are more tersely summarized. There is no intent to imply that the space given to any study is related in any way to its merit.

One of the first studies was mentioned briefly earlier. Katona (1940, P. 36) compared an "understanding" group with a "rote" group. The understanding group was given the rule and an explanation of it while the rote group was given drill without rules and explanations. It will be no surprise to the reader to learn that the understanding group did better than the rote group on a transfer test. As with other Gestalt writers (e.g. Wertheimer, 1959), the primary emphasis is on understanding and meaningfulness and not necessarily on the discovery-reception dimension of presenting information.

Another paper which was most important for its own findings, and for the future research which it excited, was again designed to compare predictions from connectionism and from meaning and generalization theory. The paper is a monograph by Swenson, Anderson, and Stacey (1949) and it presents abstracts of the three doctoral dissertations performed by the authors at the University of Minnesota. In the introduction to the monograph, Mc Connell argues that experiments on the memorization of nonsense syllables may be too primitive a base from which to generalize to human, complex, verbal learning. He suggests that studies which use "meaningful" materials may produce results which disagree with those of Thorndike.

All three studies attempted to contrast teaching procedures which were derived from the authors' interpretation of Thorndike's connectionism on the one hand with their interpretation of theory which emphasizes generalizations, the discovery of meaning, and the comprehension of relationships.

In the first of the three papers, Swenson operationalized in two treatment groups the distinction between "meaning-discovery" theory and connectionism. She added a third treatment to approximate her conception of the then current practice of the teaching of arithmetic. The subject matter was one hundred addition combinations (e.g., 3+4 and 7+3).

She assigned 332 children, who were from 14 different second grade classes, to the three treatment groups. The first group was a Generalization group. The number of combinations presented to the children in this group was ordered according to some unifying idea or generalization. She does not state what these unifying ideas were. The teachers who used this method encouraged the children to try to build up relationships among the addition facts. By grouping these number combinations, the teachers led the pupils to formulate their own generalizations. The second group, the Drill group, was presented the number combinations in different orders by the teachers. The children were discouraged from producing answers on any but an automatized procedure. If a pupil hesitated or gave a wrong answer he was instantly corrected. There was much group drill. The third group, the Drill-Plus group, was designed to approximate common practice in elementary schools. Each number combination was presented by pictures of concrete objects, and each new addition combination was followed by allowing the children to count and manipulate concrete objects. After the counting and manipulating of concrete objects, drill procedure, identical to that in the drill method, was used. The Drill Plus method also presented the addition facts in groups which were organized by the size of the sum. Again pupils were discouraged from making generalizations of number relations.

For all three groups, instruction lasted for a total of 20 weeks, and was divided into three major sections. An original set of facts (O), an interpolated set of facts (I), and a final set of facts (F) were taught. The 14 second grade classes were assigned by a stratified random procedure to the three treatment groups. A test over the 100 addition facts was given on five different occasions. Before the original learning (Test I), after the O instruction (Test II), after the interpolated learning (Test III), after two and a half weeks of vacation (Test IV), and after the final instruction (Test V). After the fifth test of learning, three transfer tests were given. One was on 100 untaught subtraction facts. The second was on a test of 100 addition problems in which one of the two numbers to be added was a two-digit number. The third transfer test presented a variety of addition possibilities with one-digit, two-digit, and three-digit numbers.

Although she reports no means, standard deviations, standard errors, and analysis of variance tables, the data appear to have been fairly well analyzed; that is, she tested for homogeneity of variance, used analysis of variance and covariance.

Her analysis of results is complicated and it includes analysis of gain scores from one of the five tests to the one which immediately preceded it. The failure to report numbers and figures and the use of the gain scores make it difficult to summarize the results. However, on the learning of the original (O) facts, the generalization group gained more than either of the other two groups. The drill group was significantly superior to the Drill-Plus group. On the learning of the interpolated (I) facts the three groups were not significantly different in gain scores. Neither were there any significant differences in gain scores on the learning of the final (F) facts, although the Generalization group performed better than either of the other two groups at the beginning of the F learning, and also at the end of the F learning.

On the learning of the three sets of facts, the gain scores were significantly different only in the case of the learning of the O facts, where the rank order was Generalization, Drill, and Drill-Plus. Each group was significantly better than the group which followed it immediately. There was no significant gain or loss in retention across the three methods for any of the retention periods.

After adjusting for MA, the transfer within the 100 addition facts favored the generalization group on most of the tests. Occasionally the Drill-Plus group transfered more than the Drill group. When adjusted for MA and initial learning of addition facts, transfer to subtraction facts ranked from highest to lowest, Generalization, Drill, Drill-Plus. All differences were statistically significant. On transfer to the upper decade facts, both the Drill and Generalization groups were statistically significantly better than the Drill-Plus group, while neither of the two former groups were statistically significantly different from each other.

She interprets her results to support Judd's generalization theory and Katona's organizational theories of transfer and to disagree with Thorndike's notions on learning and transfer. She emphasizes the importance of self-discovery by students, which apparently she feels is more compatible with generalization theory (Judd & Katona) and with Gestalt psychology than with Thorndike's connectionism.

It is clear that training which emphasized organization and which grouped number combinations in some logical fashion facilitated transfer, at least as evidence on some of her tests. Only on transfer to higher decade facts, a somewhat remote transfer test, did this effect not occur. She seems to have found that direction toward generalization coupled with reinforcement for developing and verbalizing generalizations, is better than a procedure which has no logical sequence to its materials and which does not reinforce, and may even punish, the development of verbalizations of generalizations. Her treatments varied much more than the discovery-reception dimension. The sequence and organization of materials and the use of reinforcement and punishment for verbalizing generalizations confounds any interpretation about the discovery-reception facet.

In the second of three papers in the monograph on learning theory in school situations, Anderson (1949) also tried to compare connectionism and drill with generalization theory and active discovery by the pupils. Against relatively discreet elements and drill, he compared a highly organized system of principles in which the practice came after rather than before the introduction of the principles and their rationalization. Connectionism was depicted as a sterile system which was designed to avoid the practice of errors. He alternatively described the two theories as drill theory and meaning theory (P.41).

He also used arithmetic, elementary school children and two treatments. In the Drill group there were 208 fourth grade students and in the Meaning group there were 181 fourth grade students. The experiment lasted for approximately six months. Unlike the Swenson study, in which the teachers were assigned at random to the treatments, he assigned teachers to the treatments on the basis of the educational point of view that the teacher evidenced in an interview and on a measure of attitudes. There was no day by day control over the procedure for the teachers of the treatments (P. 44) nor were the teachers held responsible for definite objectives, content, or amount of time spent on instruction and drill, etc. Instead, broad objectives were given, and the teachers were instructed by Anderson for approximately six, ninety-minute periods. He also provided the teachers with manuals to provide some structure and he insisted that they keep day by day logs of their instruction. From the logs, the teachers of the drill classes averaged about 11 minutes a day on instruction and 24 minutes a day on drill, while the teachers of the meaning classes spent about 27 minutes a day on instruction and 18 minutes on drill. Although he cannot specify precisely how the treatments differed from each other, the intent was to implement connectionism in the Drill treatment (discrete elements, response given to the learner, and repetition or drill on the discrete elements) and field theory in the meaning treatment (organized patterns, responses not given to the learner, practice at applying generalizations).

The dependent variables were tests of computational skills, problem solving, understanding of social concepts in arithmetic and vocabulary, and of mathematical thinking. The two groups were compared by the Johnson and Neyman test of statistical hypotheses. Two variables were controlled statistically. They were school ability, as measured by the Minneapolis School Ability Test, and an arithmetic score obtained from a pretest. The Johnson-Neyman Test enabled Anderson to estimate the part of the population, in terms of the control factors, which contained the significant differences.

The tests of computational skills included tests of addition, subtraction, multiplication, division, fundamental operations, and an interpolated test of subtraction. Because of heterogeneity of variance it was not always possible to give a definite interpretation of the data. The significant differences which did occur, indicated that the drill method was superior for pupils who scored low on the Minneapolis School Ability test but high on the arithmetic pretest. The meaning method tended to be superior for pupils who were high on the ability test but who were low on the arithmetic pretest. Anderson interprets this to mean that practice is probably most helpful to those who are low on the ability measure but are quite high on the achievement measure. The reason is that these students "understand" much of what they are capable of understanding and will improve primarily when given practice to help them recall quickly and accurately the facts and skills they have previously learned. On the other hand, and by the same reasoning, the students of higher ability, who are not achieving as well as might be expected, need instruction in principles rather than practice at skills.

There were no significant differences among the two groups when social concepts and vocabulary tests were the dependent variables. On the tests of mathematical thinking, the difference between the high groups favored the meaning group and was significant at the .01 level. The difference between the low groups favored the drill method and was significant at the .01 level. On a test of long division over the learning exercise, the drill method was better for both the high groups and the low groups.

Although it was not always consistent, the trend of the evidence indicates that the drill procedure was better for those people who were below average on the school ability measure and were above average in achievement in arithmetic. The meaning method was better with those people who ranked above average in school ability but were below average in achievement in arithmetic. One exception to this result is the effect of drill method upon initial learning to teach a few specific associations. Drill was effective with both the high and low ability students. To teach information which will transfer to new situations a method which emphasizes something other than drill was more effective, at least with the students with better ability but of poorer achievement history in arithmetic.

In brief, he supported , in part,his hypothesis about the effectiveness of methods which emphasize generalization and self-discovery. The generalization method may reduce recall of specific information and knowledge but may increase transfer of principles to new examples of these principles. This is a most important finding. As the reader will see, it is supported by research which was performed later. Another important finding of his is that methods interact with individual differences. All pupils did not appear to profit equally from any one procedure. Anderson hypothesizes that the meaning method might have produced even better results had his teacher emphasized understanding first and practice second. Apparently what Anderson means by a meaning method includes something different from or more than what is often meant by a discovery method, which emphasizes early practice from which principles are to be self-produced. In a study as long and complex as

Anderson's, there is little rigorous control over the independent variables, and it is difficult to draw conclusions about the learning by discovery hypothesis. His results seem to indicate that direction toward developing generalizations can increase transfer to new examples of these generalizations. At the same time, when the dependent variable is learning for a few specifics, training of generalization may not produce the best results. In fact it may produce the worst results when compared with some procedure which does specify training for generalization. As with the Swenson study, the results support grouping stimuli, sequencing them logically and allowing students to practice deriving and applying generalizations, at least when there is a history of association to the stimuli used in the experiment.

A study by Thiele (1938) also reports findings similar to those by Swenson and Anderson. Drill and generalization were two methods which were contrasted in teaching of arithmetic to elementary school subjects. The drill method emphasized memorization and punishment by the teacher for student attempts to generalize. The generalization method emphasized the students deriving their own rules. The drill group did not fare as well as the generalization group.

Forgus and Schwartz (1957) compared the learning of a code under three different conditions. One group was called a Rote Group and was not taught information about the principles. The two other groups varied in the amount of direction they were given toward learning the principle. On retention and transfer tests both of the directed groups were superior to the rote group. As was the case with the Anderson, Swenson, and Thiele studies described above, the Forgus and Schwartz study does not bear precisely upon the learning by discovery hypothesis. Their groups differed in ways other than along the dimension of discovery-reception. These studies are of interest because of their attention to intervening variables and also because they indicate that certain types of conditions are better at producing discovery than are other conditions. When direction by E is toward the rule or verbally stated basis for generalization, transfer to other instances of the rule is increased.

A development of interest in theory about sub-verbal discovery events and their effects upon transfer appears in Gertrude Hendrix's work.

In the several papers (1947, 1950, 1961) she discusses the discovery hypothesis. She too was influenced by meaning and generalization theory. However, her theoretical approach was different from that of Swenson, Anderson, & Stacey (1949). She argued that a period of "unverbalized awareness" was most important for obtaining transfer of training. Here we have transfer as an operational definition of the effect of "discovery." She indexed discovery, as described below, by facial and emotional responses. Her study is a slight refinement over the earlier ones in what is meant by the term discovery. She is still using covert responses as the treatment variables, rather than the stimuli which may or may not produce these covert responses.

In the earliest of the three papers (1947) she presents, in very brief form, her first attempt at "experimentation" with discovery learning. With eleven college subjects, and later with high school subjects and also more college subjects, she compared three treatments. In Method I the generalization was stated first by the teacher, then it was illustrated and applied to new problems. The generalization was "The sum of the first n odd numbers is n-square."

In Method II, labeled the Unverbalized Awareness Method, a series of problems was presented. First the learners were asked to find the sum of the first two odd numbers, then the sum of the first three, the first four, etc. As soon as the subject noticed (discovered?) the relationship between the totals and the number of odd numbers he was asked to leave the room. The index of his "discovering" the relationship was "he started, or gasped a little, or smiled, or grew tense--that is he showed in some way that something was happening to him . . .Further, he began to give the succeeding answers rapidly. . ." (1947, P.99). In Group III, labeled the Conscious Generalization Procedure, after Judd's writings referred to above, the procedure was same as that for Group II except that when the indices of "discovery" occurred, the subjects were asked to state the rule they had discovered. The teacher then proceeded to shape the students' verbalization of the rule until it was accurate. Two weeks later each group was given a transfer test which contained items which could be solved quickly by use of the generalization stated above. The results were expressed as a ratio between number of correct answers obtained by the short cut and the total number of correct answers. The groups ranked, from high to low, II, III, and I. A t-test showed that groups II and I differed at the .12 level and the groups II and III differed at the .34 level. In other words, no difference was statistically significant at the conventional .05 level. Hendrix, and others subsequently, have cited her study as if the statistical results were significant. However, the n was small, 40 in all three "experiments" combined. Her results neither support nor refute the discovery hypothesis nor her hypothesis about "unverbalized awareness". The hypothesis deserves further study, especially if the treatments can be carefully designed to differ from each other on a single dimension.

Thorndike's admonition to avoid the practice of errors, which may occur in discovery learning, prompted a chain of studies. Even a type of task used by Thorndike was adopted in these studies. The task involves eliminating one word from among five which does not belong. Craig (1953 and 1956), Kittell (1957) and Stacey (1949) used this type of task to study learning by discovery. Stacey studied information given before the learner made a response and also studied reinforcement and knowledge of results. The later studies concentrated more than did Thorndike on the information given before the response and less on the reinforcement variables, which were of interest to Thorndike. However, Stacey, much more than Craig and Kittell, was interested in the connectionist field theory dichotomy. Along with Swenson and Anderson, Stacey (1949) reacted to Thorndike's caution about the use of discovery. As quoted above, Thorndike cautioned that to get active rather than passive learning at the cost of practicing errors may not be a good bargain. The reason is that by discovering facts for himself the learner runs the risk of strengthening wrong habits and of wasting time.

Stacey argued that Thorndike studied reinforcement and punishment primarily because with nonsense materials there is little opportunity to vary other types of guidance given to the subjects. He argued further that provided the stimuli are "meaningful" discovery learning and active responses can enhance learning. He felt (P. 80) that Thorndike had not gathered much data about discovery situations where the material is meaningful and the learner is guided during his activity.

Stacey divided 100 sixth grade pupils into five groups which differed from one another in amount of guidance which was presented simultaneously with each learning item. Each item contained five English words. The task was to find one of the five words which did not belong with the other four because of some relationship. Group A was given no intimation as to why a particular choice was correct. Group B was told only that there was a reason why one of the words did not belong with the other four. This group was also given three examples to work before they began the learning task. With the examples appeared the correct principles and the correct answers to them. Stacey called the above two groups his "discovery" groups. For the remaining three groups, correct answers were specified in advance for each item. Group C was given only the item and the correct answer. Group D was given the items, the correct answers, and the information and examples given to Group B, described above. Group E was given the same as Group D plus the correct reason for the answer to each item. Each subject was also given immediate feedback. E announced "right" and "wrong" when appropriate. A correction procedure was used, and S was allowed to continue until he selected the correct.

He gave a pretest and a posttest, both of which were the same test. He found no interaction between amount of information given to the subjects and ability level. The subjects of the higher ability level were superior to subjects of both low and average ability levels on the gains from the first to the fifth learning trials. However, when gains from pretest to posttest were measured, there were no significant differences either among ability levels or among the five treatments.

When the dependent variable was ability to give the proper reasons for the responses , the results indicated that those given the minimum amount of information (method A) or just above the minimum (method B) and just below the maximum (method D) gave the correct reasons in a higher proportion of cases than the subjects given the median (method C) amount of information. There were not any significant differences among methods A, B, and D. In other words, the two methods which he thought involved discovery, methods A and B, produced greater ability to state reasons for correct responses. However, method D, which emphasized "identification" rather than "self-discovery" produced similar mean scores. He interprets his results to support strongly the process of self-discovery, not to support the process of "authoritative identification", and to indicate that errors made in the process of self-discovery are not as detrimental to learning or achievement as are errors that were made when correct responses were identified for the learners. (His results in the use of reward and punishment tended to support Thorndike' s position. Rewards were effective for learning and punishment was not effective in weakening or eliminating errors.) The results appear to contradict those of Judd and Katona.

Stacey' s results indicate one danger of labeling the stimuli in terms of behavior which one hopes the stimuli will produce. Groups C and D might also be considered "discovery" groups if it is discovery of a generalization or principle rather than specific answers which is most important. Neither C nor D was given the correct principles.

Although Stacey (P. 74-77) is interested in the Thorndike vs. Field Theory issue his study differed from those of Swenson and Anderson in several important ways. He seems to have been more concerned with the discovery-reception dimension and less concerned with the comparing of the two theories of learning. Stacey (Pp. 74-80) tried to describe several dimensions in the learning situation: the degree of self-discovery, the amount of guidance, the type of material (meaningful or arbitrary), the time the information is given to the subject (the reward or punishment given after a response and the guidance given before a response). His attempt to describe some of the independent variables led him away from describing the materials in terms of responses they are supposed to produce. He also measured several different dependent variables, as described above, including a measure of ability to produce the reasons why answers were correct. It also led him to describe "discovery" largely in terms of stimuli other than reinforcement and punishment. However, when he analyzes his results, he writes about certain groups as the "discovery" groups.

Stacey's study influenced a series of later studies. Craig (1953, 1956) and Kittell (1957) used the same type of task and continued Stacey's preference for describing the independent variables in terms of the guidance they produced.

It should be remembered that Stacey's results appear to contradict those of Judd, Katona, and others to come below. The reason or reasons for the contradiction are not apparent. The studies tend to differ from one another on many dimensions: type of task, age of learner, amount and type of guidance, regardless of how it is labeled, and amount of transfer involved on the final test.

Stacey began to break away from the testing of connectionism and field theory. The break was carried much further by Craig in two studies.

Craig (1953) reacted to the line of argument developed by Stacey. Craig felt that guidance could produce a positive effect on discovery. He described his independent variables as different types of stimuli and his dependent variables as learning, retention and transfer. This description of variables represents an important step towards defining more precisely the learning by discovery issue and a step away from the "rote-understanding" issue, and the definition of treatments in terms of responses made by the learners.

He investigated the effects of cues about the correct principles or bases for correct responses upon transfer. There were four groups of fifty male college graduates. The task was the same as that used in the study by Stacey above: i.e., to determine the one word among the five of each item that did not belong. The first group was a minimum guidance group and was given no clues. For the second group the items were grouped according to common principles to serve as a clue. The third group received a blank space between the sets of items which were grouped by a common principle. This group was told that all items in a group were organized into a common principle. The fourth and final group, the maximum guidance group was given the same information as that described for the above groups but was also given a short statement of each principle.

On initial learning, the amount of guidance was directly related to the number of correct responses. When transfer was a criterion, the same relationship held; that is, the more the clues, the more the ability to discover.

As the items became more difficult, the effect of guidance was changed somewhat. The maximum guidance group was better than any of the other three groups. There was no statistically significant difference among any two of the three least directed groups when the difficult items were compared with the less difficult items. However, increasing the amount of guidance did not decrease the correlation between initial ability and transfer. About one third of the variance on the transfer test could be accounted for by the scores on the test of mental ability.

Craig (1956) explored further the effects on retention and transfer of direction in learning. Although directed discovery produced results on initial learning, he hypothesized that it would also produce an increase on retention and transfer without producing a loss on initial learning. In the second experiment (1956) he divided 106 college sophomores into two groups, a no-help group and a directed group. The no-help group was told only that one principle was used to answer all five items which were grouped together as a unit. The directed group was given the same information as the no-help group, except that the principle was stated above each group of four items. Each item consisted of five words. The subject was to sort out the incorrect one of the five. He gave an immediate test and retention tests three, seventeen, and thirty-one days later. On the immediate test the directed group did better than the no-help group. Although there were no significant differences between the two groups on the three and seventeen day retention tests, there was a significant difference between the two groups on the thirty-one day test.

The directed group did better than the no-help group. These tests all contained new examples of the rules previously learned. Another retention test, which consisted of new rules and examples of these new rules produced no differences between the groups. He interprets his study to indicate that "external direction" can help learners to make future discovery by providing them with an adequate background of information.

In his own words Craig summarizes his experiment as follows.

> Many have advocated relatively independent problem-solving in the belief that learning situations should be similar to anticipated transfer situations. This point of view rests on the assumption that future discovery of principles will be through independent problem-solving, hence, more like pupil self-discovery than directed discovery. A different view is that problem-solving and discovery are never independent except in the sense that no one is physically present to prompt the learner. Principles previously learned in an area serve to direct discovery. Out-of-school discovery is not independent but directed by the knowledge gained under the direction of previous teachers. The more direction of this kind available to the learner, the more effective his discovery of new relations. The cumulative effect of greater learning through directed discovery over months or years may offset the effect of any lack of similarity between learning and transfer situations and prove to be the best preparation for new discoveries. (Craig, 1956, P. 233).

Of course it should be remembered that he found no effect on transfer to new principles, a finding which has been often repeated by other researchers. He also found no differences on two of his three retention tests.

Corman (1957) performed a study which was also primarily interested in relating the stimulus variables to learning and transfer.

To study the effects of guidance upon problem-solving, Corman used forms of Katona's match tasks which were presented to twelfth graders. He varied the information about the principle "no information;" "some information;" or a clue and "much information" or a statement of the principle) and also the information about the method of solving examples (no information; some information; much information). All possible combinations of these two types of information gave nine different treatments ranging from no information about either the principle or the method, to information about both principle and method. The dependent variables were initial learning, transfer to simple and complex problems, and ability to verbalize the principles.

His results are complicated. For the simple transfer problems, specific information about the rule with an indirect clue to the method or indirect information about the rule with explicit information about the method, was the best for the more capable students. On the test of complex transfer the indirect clues, either to method or to the rule, produced for the more capable students performance worse than other combinations of information. But for students of less than average ability, performance on complex tasks was best when guidance either specific or less explicit, was given about the method. When acquisition of the rule was a criterion, *performance increased as the amount* of information about the rule also increased. That is, explicit information about the rule was superior to no information about the rule.

When writing the rule was the criterion, the students who were given the most explicit information about the rule performed best, although their performance was better only than that of the "no-information" group. No statistically significant effect on this criterion was found for information about method. Corman concluded that appropriate guidance was beneficial for learning and transfer and that failure to provide it would delay rather than prevent solution; and that the effectiveness of the guidance may interact with student ability as described above.

One interesting part of this study was the attempt to operationalize the independent variables in terms of two types of information (information about principle and information about methods of solving problems) and three quantities of information (no, some, and much). His attempts to define operationally the treatments in terms other than those which also describe the type of responses (rote or discovery) these treatments tend to produce, represents a step toward objectivity in description of the independent variables. However, such terms as some and much leave some or much to be desired because they are at best on an ordinal scale, and also because they still are defined in terms of assumptions about the learner's background when these assumptions may not be valid.

Another interesting part of the study was a dependent variable, ability to verbalize the principles, which he added to the usual dependent variables of initial learning and transfer to new problems. This study extends the earlier ones mentioned above by refining the independent and dependent variables in problem solving and in learning by discovery. The refinement was in the sense of elaborating the number and type of variables and in studying all possible combinations of the independent variables. He was less interested in the theoretical controversy discussed above which occupied Swenson, Katona, and Hendrix.

The primary interest in dependent and independent variables rather than in intervening processes, which was characteristic of Corman's study and of the two Craig studies mentioned above, is supplemented by a study by Kittell. He hypothesized that giving the underlying principles, in verbal form, was better for transfer and retention than not giving these principles. He used the same type of items as did Craig. He used 132, sixth grade children divided into three groups, a "minimum" group, an "intermediate" group, and a "maximum" group. The minimum direction group was told that each group of three items had a principle in common and was told to look for the principle. The intermediate direction group was given the same direction as that given to the minimum group plus a verbal statement of the principle. The principle was printed above the items to which it referred and was also read twice, aloud, by the E. The maximum direction group was given not only the same information as the intermediate group but were told by E the three correct responses to the three items in each group.

On a difficult test of transfer to new examples of previously learned principles, the intermediate group did the best, the maximum group next best, and the minimum group did least well. The intermediate group also retained more of the previously learned principles. On initial learning, the intermediate and maximum groups did not differ from each other significantly and each was better than the minimum direction group. His tests were difficult. The mean scores were less than five out of a possible fifteen.

Compared with Craig's two studies, Kittell increased the amount of direction by adding a group which was given both the relevant rules and the correct answers. Kittell's intermediate group was actually more highly directed than was Craig's "directed" group.

His results offer an interesting hypothesis about the relationship of direction to transfer. The hypothesis would be that when the material is most difficult the direction should match the population of items to which transfer is desired. For example, direction with specific rules produces transfer of these rules, even to situations where the rules do not apply.

That the most highly directed group would do as well as or better than any other group on initial learning of several specific responses agrees with much earlier research and is a surprise to no one. It is interesting that the group given the rules but not the correct answers produced the greatest transfer to new examples of the same rules. Perhaps the learner discovers how to apply the rules and receives extinction for incorrect attempts to apply these rules. The direction toward certain rules probably makes it more likely that he will use these rules again in the future. One wonders what Kittell's results might have been had he used one transfer test which contained quite new and different situations and another test which contained simpler items. One might predict that the least directed group would probably have done the best on the former test. However, Craig and Kittell's studies also show that labels such as "maximum" and "minimum" are helpful only within a given study. Kittell's intermediate direction group was more highly directed than was Craig's (1956) "maximum" group. By attending less to theory about intervening process, one does not automatically produce more useful labels than "rote" or "discovery" to describe the treatments. Labels such as "intermediate" or "same" can be confusing to readers.

From the studies by Craig and Kittell it seems that transfer, at least to new instances of previously learned concepts, can be increased by certain types of direction from E. This is true when the direction allows the learner to practice applying the concept and does not specify correct answers for him. Unlikely as it may seem, in several ways Kittell and Craig's directions toward concepts and generalizations are like the training procedures advocated by Judd, Katona, Swenson, and Anderson.

It was inevitable that the Craig and Kittell studies (which found that by giving rules transfer could be increased) would excite at least one rebuttal. Haslerud and Meyers (1958) questioned the findings of Craig and Kittell.

Haslerud and Meyers (1958) used 100 college students as subjects, and 20 enciphering problems as the learning task. The two treatments consisted of either no directions or specific directions (including the rule) for deciphering the code printed above the problem. They used a treatment by subjects design; that is, each subject was given both treatments. There were ten items for each treatment. On initial learning the specific directions produced the greatest mean performance on the test of transfer to new sentences, which involved the same 20 rules used during training. They found no statistically significant difference.

However, they give a dubious interpretation of the results and conclude that the "No-Directions-Given" treatment was the better of the two because the percentage of loss from the immediate to the test given one week later was less for this group than for the other group. Since each subject was given practice on each of the two experimental conditions, one might expect that the practice at discovering would generalize from one set of items to the other and that the treatments would then be contaminated. Again, the directed procedure was better on the original learning, even when there was no significant difference on a later transfer test.

From the Haslerud and Meyers study above, and from the studies of Kersh and Wittrock, to be described below, it seems that the discovery groups fare quite well when gain or percentage of retention is the measure of the dependent variable. Perhaps this is because the discovery treatment is very much like the test for the dependent variable. That is, as Craig (1956) described in his article summarized above, the need for transfer from learning to testing is less with a discovery group. Perhaps this is only a regression effect, perhaps it comes from a very general transfer effect--a learning how to learn, or perhaps it means that the trials given during learning were insufficient to allow the discovery groups to learn. The answer to this problem is not known.

Haslerud and Meyers showed more interest in theory about transfer and discovery than did Craig, Corman, and Kittell. The following studies from the University of Illinois also indicate definite concern for theorizing about the type of learning behavior which the treatments will excite. Their use of two rather complex experimental treatments, which differ from each other in several ways, remindsone of the earlier studies of Katona and Swenson. However the studies which follow represent substantial improvements in methodology over some of the earlier work.

These doctoral dissertations (Grote, 1960, Moss, 1960, Ray, 1957, Rowlett, 1960, and Tomlinson, 1960) report work on guidance and its effects upon transfer. Ray's study will be reported in detail as an example of these experiments. He had two treatments, Direct and Detailed Instruction being the first and Directed Discovery being the second. He had three student ability levels, high, medium, and low. All the 158 subjects were assigned individually, at random, to the two experimental and one control group. The dependent variables were initial learning, retention, and transfer. The latter two were measured one week and also six weeks after instruction. The 47 minutes of instruction which was about a one inch micrometer caliber was presented by slides and by magnetic tape. The two methods differed in that the Direct and Detailed procedure included step by step procedures in the solution of the problems. Principles were given verbally by the teacher along with several examples. In the Directed discovery procedure, the learner is told what he is expected to learn and is given problems to solve. Both groups have aids, equipment, and micrometers. By analysis of variance he found that the Directed discovery method was better than the Directed and Detailed procedure for transfer (both tests) and for retention (both tests). There was no significant difference on the initial learning test, nor was there an interaction with ability level.

Rowlett's (1960) results support Ray but Tomlinson (1962) and Moss (1960) found no difference between these two treatments, Directed discovery and Direct and Detailed, on retention and transfer measures. Grote (1960) found an interaction between mental ability and method. The Directed Discovery procedure was better for average ability students while the Direct and Detailed procedure was better for the high ability students. Since in all these studies all differences in retention and transfer which were significant favored the Directed or Guided Discovery condition, as a whole they lend support to the discovery hypothesis, at least to a carefully directed type of discovery.

As with all studies that contrast two complex treatments, it is difficult to explain why one treatment was better than another.

Kersh (1958 & 1962) presents two studies in which he was primarily interested in intervening processes of discovery and less interested in elaborating the independent variables into all possible, logical combinations. But Kersh's work indicates quite a new interest and refinement in conceptualization about the intervening processes. He argues that "meaning" may not be the intervening variable which is most important in discovery learning. Instead, motivation may be the construct most useful in explaining the results. In particular, competence motivation may be a useful way to describe the intervening events produced by the treatments labeled the "discovery" treatments.

In his first study (1958) 60 college volunteers were divided at random into six groups. Each subject was taught two rules of addition, the Odd Numbers Rule and the Constant-Difference Rule. All the groups were given general instructions which specified the two types of problems, that there was a different rule for each of the two types, and that the first type of problem was called the Odd Numbers Problem while the second type of problem was called the Constant-Difference Problem. They were then given a sample of the respective types of problems and were told some of the characteristics of the number series which occurred in the problems. Then the three groups, each with two different forms for the presentation of the problems, were given their first problem. The "No-Help" groups were told to try to discover the rule. The two "Direct-Reference" groups were told to discover the rule and were given some hints about the rule. For the two "Rule-Given" groups the problems and rule were given by E. Each group then continued to work on six problems. Some of the individuals in the no-help groups were unable to discover the intended rules within the time period of 90 minutes. Immediately after the learning period the first test was given. A retest was given to all subjects four to six weeks after the first test. On the retest, two problems were presented. The first problem asked each subject to sum the first 35 odd numbers. The second question asked them the sum of all the first 35 numbers. However, the dependent variables which interested Kersh were the answers to the following questions. "Did you add the first thirty five (odd) numbers to get the answers? (yes or no). If your answer is no, explain how you explained your answer." "Did you try to recall a rule you learned (or attempted to learn) under our directions several weeks ago? (yes or no)." "Were you successful in recalling the rule? (yes or no)." His primary interest was on the method used in solving the problems, not whether or not the correct answer was produced. He found that on the test of transfer to new examples of rules ($p. < .05$) a greater incidence of "acceptable methods" was produced by the No-Help group than by either the direct reference group or the rule-given group. On a dependent variable which asked S to explain the rule, he found that only a small percentage of any group could "explain" either of the two rules. Initial learning was best for the directed groups. He interprets the data to indicate that the Direct Reference Group produced the greatest incidence of understanding. Motivation and consequent practice was greatest for the discovery group and therefore produced the best performance on the "acceptable methods" test which was given approximately one month after learning.

Several features of this study should be mentioned. One clear result of the study is that none of the treatments used was very effective at producing transfer to new problems several weeks after learning. The second is that the self-report data on motivation and practice are difficult to interpret and may not be very reliable. The third is that the motivational explanation for the performance of the discovery groups is an interesting hypothesis.

Perhaps more important than any of these, is the fact that considerable guidance was given to all groups before they were allowed to begin to work on problems. They were all told the names of the types of rules and were given some experience with examples of the rules. It may be that Kersh has introduced into this study the effects of retroactive inhibition.

In his second study (1962) Kersh definitely was studying the effects of retroactive inhibition. He used the same two rules and taught them to high school subjects by a program booklet procedure. There were 90 students in a high school geometry class. After the rules were taught and practiced by each group, one third of the subjects was given individual guidance in discovering an explanation for the rule. This was the Guided Discovery group. The second 30 students were given an explanation of the rules in a programed booklet. This group was called the Directed Learning group. The last group, the Rote Learning group, was given no further instruction. The tests of retention and transfer, given three days, two weeks, and six weeks later favored the Rote Learning and Guided Discovery group. From the questionnaire, it appeared that the Guided Discovery group practiced rules after learning and before testing more than did the subjects in the other groups.

In both of Kersh's studies it appears that some kind of directed discovery of explanations or relationships motivates students to continue after the learning exercise is completed. As in the first study, Kersh again used as the primary dependent variable the method which the students used to arrive at their answers to transfer items. Although this is an important index, especially to those interested in indexing the intervening variables, one must remember that this is not the same index of transfer which is often used in other studies on learning by discovery. In his second study, the label "rote learning" was used to describe a control condition in which no instruction was given. This labeling certainly differs from that of earlier studies where rote learning was made synomous with drill and repetition.

Kersh's work is of much interest because it represents recent experimental attempts to index the intervening events which may mediate the transfer which is supposed to be a characteristic product of discovery. His attention to motivation, which in later writings is described after White's (1959) concepts of competence and effectance, is an important refinement in approach toward explaining or describing an intervening event. As is characteristic of the research on discovery which is primarily concerned with intervening processes, one finds little attention given to careful dimensionalization of the independent and dependent variables. One result is that the terms "rote" and "discovery" occur frequently as labels for treatments. Another is that important dependent variables, which are scarcely employed otherwise, become the primary variables of interest because they are more likely to index the intervening events. Kersh makes one acutely aware of the problems of measurement of intervening events such as motivation.

Gagné and Brown (1961) taught 33 males, in grades nine and ten, a program on some principles pertaining to a number series. All three experimental groups received an introductory program which was followed by one of three programs. The first treatments were labeled "Rule and

Example". The second was labeled "Discovery" and the third "Guided Discovery". The Rule and Example program began with the correct formula, which S was asked to copy on his answer sheet, and was followed by several examples, which S was asked to work. The Discovery program began by asking S for a rule for the number series. The following frames contained hints which further directed him to work at deriving the rule. The questions became more and more explicit; however, they never stated the rules for him. The Guided Discovery program also began with a question, but the question was more specific than the one asked in the Discovery program. The first question was followed by a second which introduced numbers and which made the process of deriving the rule somewhat more apparent than did the Discovery treatment. Further items gave examples of the relationships within the number series.

On the second day each S went through the same program that he had studied the first day. In this respect even the Discovery group was given considerable direction, since they had seen the items and had been asked to produce the rule the day before. Gagné and Brown state, "The procedure employed with the three learning programs assured that, although the Ss responded to different sets of learning materials, they all achieved successful answers to questions about the same four number series. " (P. 316).

The dependent variables were time to solve the problems, the number of hints required to solve the problems, and weighted time score combining these. In each case S had to derive the formula for the sum of n terms in a number series. This type of dependent variable differs from those often used in studies in learning by discovery, where the subject is required to use a previously learned rule to work specific problems, because it involves transfer of a more remote nature--transfer to "new" rules.

Their results showed the best performance for the Guided Discovery group, the worst for the Rule and Example group, and intermediate performance for the discovery treatment. All measures were significant by analysis of variance at less than the .01 level. Their results support a Guided Discovery procedure for the teaching of the derivation of new but related rules. However, one must remember that all the groups were given a considerable amount of direction and a second day's rehearsal over the material which was fairly carefully directed the first day.

This study is probably one of the most carefully controlled of the studies on the intervening processes in learning by discovery. They describe the intervening variable in terms of its history for the subject. The concepts newly learned in an experiment are the "mediators" which should affect problem-solving and transfer as measured later. From this line of argument they state that, provided the concepts are learned, it should not matter on a later test how the concepts were learned. The result should be the same. It is not how you learn but what you learn that is important, according to the argument (P. 320).

Their discussion of the importance of what is learned rather than how it is learned scarcely seems appropriate for this study. This is especially the case since they were careful to mention, as stated above, that all groups learned to approximately the same criterion, and therefore must have differed only in terms of "how it was learned". Their study is important, among other reasons, for its attention to the theoretical issues, for the description of the independent variables, and for the inclusion of a remote transfer test.

Della-Piana and Eldredge (1964), after a careful analysis of the Gagné and Brown tasks and programs, question the interpretation that the differences in their study were due to "what" was practiced rather than "how" it was practiced. Their analysis is recommended to the interested reader.

A study by Bruner (1961) represents a recent theoretical approach to the study of discovery as an intervening event. He used the concept of mediation to predict the results of learning a list of paired associates. Generic mediation (a superordinate term or idea is the mediator), thematic mediation (a theme or story is the embedding material) and part-whole mediation (e.g., a sentence containing a word "trees" mediates between chairs and forest) were three types of mediators he intuited and used to measure childrens' preferences for mediators.

He taught the 30 paired-associates to three groups of twelve-year-old children. The first group was told to remember the words. In the second group, each child was asked to select some word or mediator which could help to make the association meaningful to him. The third group was supplied with the words selected by the second group and was directed to use these words as their mediators. Since the second group learned in one trial the greatest percentage of the paired associates (95%), Bruner concluded that discovery was a method superior to prompting or direction.

The mediators for the second group, by virtue of their selection by the learners, were very probably more strongly associated with the stimulus terms by the members of the second group than they were by the members of the third group. Association value is a factor which might have been a factor important in producing the results which Bruner noticed. One of the ways in which discovery learning may be effective is that it allows, and in fact depends upon , the individual associations which the learners bring to the problem. It would be interesting to perform this study after controlling for the individual differences in associations. Bruner' s dependent variable was initial learning of a list of paired associates. Percent learned in one trial is not a type of measure (transfer or of ability to solve problems) which is commonly used to sample results of learning by discovery.

The study is reported very briefly near the end of his article. No specifics about method or analyses of results are presented.

Bruner' s study is important, among other reasons, because it represents a beginning attempt to apply mediation theory to the study of discovery. As a by-product, one can see why self-selection of mediators may be an effective way to increase learning.

The associations which a subject brings to the experiment are certainly important variables.

A study which was designed to relate independent and dependent variables, but not primarily to study intervening processes, was one by Wittrock (1963). He gave to 292 college students one of four treatments. The task was to decipher transpositional codes. To one treatment the rule as well as the answer to the specific item were given stimultaneously with the encoded item. To a second group the rule was given but the answer was not given. To a third group the rule was not given but the answer was given. And to the fourth group, neither the rule nor the answer was given. From the Kittell study, it was hypothesized that with difficult materials (low-association value also) direction toward the rules or specification of the rules enhances transfer to new examples of these same rules. It was also hypothesized that learning both rules and answers would produce the greatest initial learning of a few correct answers, but would interfere with transfer, because S would not be practicing applying a rule or extinguishing his associated and incorrect answers. It was also hypothesized that the least directed group, the no rule or answer given group, would perform the best on a test which involved transfer to rules other than transpositional rules. Although it was not possible to test the last hypothesis, the results strongly supported ($p. < .01$) the other hypotheses. An intermediate amount of direction produced the greatest retention in transfer but the maximum direction produced the greatest initial learning. The minimum direction was least effective on initial learning, retention, and transfer.

He also found that the least directed group showed a gain from the initial posttest to a three-week later retention and transfer test. This last kind of result has been found before, by Haslerud and Meyers (1958), and by Kersh (1958).

Wittrock concluded that verbal direction may be used in some situations to enhance transfer by eliminating incorrect responses which may produce negative transfer. From the study it appeared that the verbal direction should match the criteria. This study offered some of the advantages which accrue to a design which tries to relate functionally independent and dependent variables. However, it offers little for the conceptualization of the intervening events or mediating events or for the study of associations which may make one procedure more effective than another. This study also exemplifies how the studies primarily interested in relationships between independent-dependent variables have recently tended to use materials which are simple, of low association value, and somewhat foreign to the type commonly used in elementary and secondary schools. The use of coding or of selecting one word from among five as tasks for experimentation is justified when one needs control over stimuli which he cannot get with sequenced materials. However, one pays a price in ability to generalize for the use of these materials.

From the work with college students described above, Wittrock hypothesized a positive relationship between the "specificity" of a verbal cue and the type of transfer obtained. This hypothesis was tested in a series of experiments (Wittrock, 1964; Wittrock, Keislar, and Stern, 1964; Wittrock and Keislar, in press). The series attempted to combine mediation theory with interest in predicting functional relationships between independent and dependent variables.

It was hypothesized if one controlled, or knew, the associations which students had to these words, he would be in a position to predict how these words might mediate transfer, learning and retention. One way to measure and to control the previous associations which learners have is to take stimuli which are relatively unknown to them and to teach a hierarchy of associations to the stimuli. In the first study in the series (Wittrock, Keislar and Stern, 1964) 52 kindergarten children were taught over a period of three months associations to the verbal cues which were to be used later in the experiment. By looking at pictures of twelve common objects and animals, and by hearing their French names pronounced aloud, each child was taught to say the French names whenever the appropriate picture was presented. Half of the twelve French names were masculine nouns and half were feminine nouns. After each child had learned to label the pictures, the next level of the hierarchy was taught. The children learned that each French name had an initial "la" or "le" sound. They were taught to say la or le and to discriminate la or le when a French name was spoken. Finally they were taught to associate the words la and le with the word article. During the experimental training all treatment groups were given a sequence of slides each of which showed three pictures, a model at the top and two alternatives below. The children were asked to select one of the two bottom pictures which matched the top picture in a certain way. (The basis for matching was always the gender of the French name at the top picture.) One of the alternatives at the bottom always had a masculine name and the other always had a feminine name. While they looked at each slide the verbal cues were presented. The children in Group I were told to "Press a Button." In Group II the children were told the word "Article." In Group III the children were told "La" or "Le" depending upon the correct basis for matching. In the fourth group the children were told the correct alternative.

The dependent variables were measured by learning and transfer tests given immediately and also three weeks later. The learning test consisted of items constructed from the six objects used during the experimental training. The transfer test used only the other six objects which had been named by the students during the preliminary training but had never been used during the experimental training. By analysis of variance and by a specific comparisons test, the mean of the group which was told "la" or "le" was statistically significantly greater $(p. < .01)$ than any of the other three groups on the transfer test.

Apparently, after the preliminary associations were learned , transfer to new instances of the same concept was facilitated by explicit verbalization by E of the name for the correct concept, followed by practice and reinforcement for applying this label. The study indicated that kindergarten children may not learn and transfer if they are given only general or very specific cues and if they are left to discover answers on their own at least when the stimuli are of common objects. It should be emphasized that all tests presented problems with no verbal cues. The child had to discover the correct basis for answering any set of ten or fifteen items. The study also indicated that whether or not discovery is effective probably depends on the learner' s history of associations to the items and the cues. A history of working with similar problems and similar materials may make discovery learning or reception learning a more effective way than the other to solve problems.

The second study in the series (Wittrock and Keislar, in press) used 160, second and third grade children. The intent of the second experiment was to find which of the cues used in the study above would produce the best transfer of ability to discover when familiar methods were used rather than materials which were taught during the experiment or during a preliminary experimental period. The familiar concepts used in this study were color, size, shape, and number. The dependent variables were again the same as those mentioned above except that one which sampled transfer to new concepts was added. The new concepts were the direction in which the apex of a triangle pointed, the texture of the interior of a triangle, and the type of border around the triangle and a bar.

The interesting result of the study was that by analysis of variance and covariance both the group given the "specific" cue and the group given the "concept" cue did significantly better than the group given the most general cue. This was true on the tests of learning, transfer to new instances, retention, and the delayed test of transfer to new instances. None of the groups was any better than any other on the transfer to new concepts test. It seems that when the subject has a history of associations with cues he can use these past associations to help him eliminate many possible answers and can discover on his own. At least he appears to be able to do this more readily with familiar materials which have few different dimensions than with materials that are learned over a few days or months during an experiment. In both studies the group given the name for the concept did as well as or better than any of the groups.

In both studies, the most general cue was not effective on initial learning, retention, and transfer, including transfer to new concepts. This may simply mean that in order for the general members of a hierarchy to become effective cues in problem solving, some procedure other than what was used in this study must be attempted. With proper training, it may be possible to make these most general cues effective on transfer to quite different concepts than those learned in the experimental training.

From these two studies the subjects history and associations to the terms E gives him appear to be important variables. Certainly these associations and those associations S has to the entire problem stimulus are variables which must be considered in future research.

It is also apparent that discovery may proceed inductively from specific cues or deductively from general cues. As a description of an intervening event, the term "discovery" may include two or more quite different processes.

Summary

From the above sample and post hoc analysis of empirical research, how does the learning by discovery hypothesis fare? What progress has been made in conceptualizing the intervening variables and in developing functional relationships between the independent and the dependent variables?

If one assumes that the grouping of studies used in this paper is defensible and not just convenient, several trends in results are apparent. Please remember that in almost all the studies, E maintained control of the sequence and arrangement of stimuli. "Discovery" has not often referred to self-selection of stimuli by S.

The recent interest in the intervening variables has changed much from the early studies on connectionism-field theory and rote-meaningful processes. The intervening variables of much interest today include motivation, verbal mediation, and even sub-verbal awareness.

As a description of an intervening process "discovery" now competes with verbal mediators, concepts, and the competence motive. Discovery is now seen as an event which should mediate transfer--a theory of transfer. There is also interest in indexing discovery separately from the transfer which discovery may mediate.

But probably more important than these trends is the recent attention (Bruner, 1961) to the history of associations which a learner brings to the experiment and their interaction with the outcomes of the experiment. Certainly much attention is needed on the individual difference variable and on proactive inhibition-facilitation as they must occur in studies on learning by discovery. In brief, the original hypothesis seems terribly oversimplified. Many facets have arisen to complicate the simple S-R and field theory dichotomy. As a way to learn or to teach, rather than as an important objective, discovery learning may or may not be an effective model for predicting functional relationships between stimuli and responses. Banal as it may sound, the usefulness of the model depends on many factors, some of which have been identified. For the future, one can hope that interest in intervening processes will lead the researchers to select for experimentation dimensions of stimuli which are relevant to student performance on the dependent variables. There is need of combining interest in the intervening events with interest in establishing functional relationships. Duncan (1959) stated that research on problem solving had neglected the functional relationships between stimuli and responses. Research on learning by discovery has had interest in theory and in functional relationships. It now needs both in combination with each other.

The identification (but not the measurement) of the dependent variables has progressed considerably, much more than the identification and indexing of the intervening processes. However, the great variety of dependent variables, and the researchers' proneness to differ from one another in their selections from among these dependent variables, make it most difficult to relate or to synthesize results of the studies.

What are some of the functional relationships between stimuli and classes of responses which, although tentative, seem to follow from the empirical research on the hypothesis?

The first is that the conclusions are related to the type of dependent variable which is sampled. When initial learning of a few specifics is the criterion, highly directed procedures seem to be most effective, or as effective as any other approach. When transfer to new instances of the same, few previously learned concepts is the criterion, guidance toward the concepts or generalizations is probably the most effective type of procedure.

When transfer to new concepts, originality, etc., are the criteria, almost nothing is known about the effects of treatments, except that most of them are quite ineffective. However, few studies have used this important dependent variable. In a very important sense, the discovery hypothesis is untested because of the notable neglect of this important type of dependent variable.

Another conclusion is that when there is a high association value to the stimuli, the effects of learning or teaching by discovery are different from those obtained with low association value. Difficulty level, another variable, also seems to effect the results. It is too early to state the direction of the results. It is appropriate only to note that individual differences in associations and in difficulty are important but neglected variables.

Another conclusion is that discovery may be a highly motivating or a highly frustrating experience. There does not seem to be a middle ground as far as affectivity is concerned. However, the data are meager on the motivating effects of discovery learning.

From among many possibilities, one can suggest several things for the future. The development of measures of individual differences in ability to discover is a most important problem. Part of the problem is that the dependent variables of interest to people who study learning by discovery are not always clearly defined nor are they the same from study to study. For example, Kersh was interested in the methods the students used to solve problems, while other researchers gathered data about the number of correct answers, regardless of the methods used by the students. Some researchers are interested in the child's ability to solve problems which were examples of previously learned concepts and other researchers are interested in the child's ability to solve problems much different from those he encountered during the experiment. Gagné and Brown were interested in the child's ability to derive formulae rather than in his ability to solve numerical problems. How comparable to one another are these dependent variables?

It would be helpful if studies on learning by discovery were to use time as a dependent variable more frequently than they have in the past. It would also be helpful if they were to use savings as a criterion more frequently than they have. That is, the learning of a second and more advanced topic in a field could be used as a dependent variable to measure the effectiveness of a learning by discovery treatment. There is no need to restrict the variety of dependent variables. But there is a need to relate ones findings to the particular dependent variables used in each study.

A change should be introduced in the study of ways to teach discovery as an important end in itself. Perhaps there should be further attention to the transfer effects produced by self-selection of materials as one of the treatments which may allow a student to develop this ability to discover.

Another way to state this change is as follows.

Instead of asking if learning by discovery is or is not as effective as some other way to learn, one ought now start to ask by what sequence of directed and undirected experiences can we teach children how to learn to discover, if indeed this ability can be developed at all?

At least several people are recently becoming interested in this latter approach; for example, Bruner (1964a and 1964b), Suchman (1960 and 1961) and others as summarized in Flavell (1963). Unfortunately these attempts have not been very successful to date, but they are important enough that they should be continued.

But as of the present, what does the empirical research on discovery learning imply for teaching by discovery? It seems that some type of carefully sequenced, guided discovery is a sound compromise and combination from the realms of motivation, efficiency, and transfer within concepts. In terms of the results from the empirical research, the curriculum projects which present carefully sequenced and hierarchically organized material and which require the learner to verbalize his own generalizations are defensible because they retain the feeling of self discovery and combine it with an efficient program of direction aimed at transfer.

V. Related Studies

Most of the research on learning by discovery has not built upon or been related to the research on concept formation, problem solving, and transfer of training. Many of the independent, intervening, and dependent variables studies in the research on learning by discovery are also studied in the areas mentioned above. In addition, some of the studies on verbal mediation and mediated generalization are relevant to the process called "discovery."

The papers which are reviewed below are organized as follows. First, is a brief section on the dependent variables which is followed by one on the intervening variables. The third section is on the independent variables. In it are discussed variety of stimuli, language (including verbalization by E and by S, and instructions) learning set, and individual differences. The fourth section is on applications of these variables to teaching and training. The studies in section four are complex and do not fit neatly into any one of the first three sections.

Dependent Variables

Among the most important of the dimensions of the dependent variables, which are often measured in studies in learning by discovery, are transfer and savings. Whether it is problem solving ability or particular content which it is measured, the interest always centers upon the presentation of something new, a problem, a concept, or an example of a previously learned concept. In this area of dependent variables, considerable research and thought is needed to devise tests and measures. Gagné, Foster and Crowley (1948) reviewed the area of the measurement of transfer of training and summarized the methods which have been used to quantify transfer of training. Another useful comment on the measurement of transfer of training is presented by Jensen (1964), which will be discussed later in section four.

Comment

Cronbach (1958 and 1964) argues for a multi-dimensional approach toward measuring the outcomes of learning. In research on learning by discovery, a multivariate analysis of the effects is most needed. Time, motivation, savings, and transfer are all measures which should be included in studies on learning by discovery. It is important that a student learn to solve problems, but it is also important that he be able to use the subject matter to further his learning in the same area and to avoid problems in that area. It is also important to know how much can be produced in a given amount of time. Aside from its obvious importance to educators, time has a rather important measurement property--it is a ratio scale.

Just as Della-Piana and Eldredge argued for standard types of treatments which could be used to compare one mode of presentation with another, one can argue for the development of standardized measures of dependent variables used in learning by discovery. At present there are very few of these types of measures of achievement, which are available for researchers in learning by discovery. The immensity of this problem is apparent, and its solution is important to the future research in this area. Glaser has written and spoken often on this problem.

Intervening Variables

One reason why learning by discovery has created such a furor and interest among educators is that it poses an intervening variable, an event called discovery, while at the same time it is a theory of how and under what conditions associations and knowledge are acquired. There are not many theories of verbal learning which predict on theoretical bases, rather than on empirical bases, under which conditions associations will be formed. For example, mediation theory (Osgood, 1953) predicts behavior after associations are formed. That is, if A is associated with B and in turn with C, then there should be a tendency for C to be produced to the stimulus A. From the theory one knows little about how to associate A to B and B to C. In that the event called "discovery" leads a researcher to study a certain independent variable because it is supposed to produce the event of discovery, the theory appears to be useful. However, in that the term discovery is used to describe implicit mediating responses, it is a vague, and in the author's opinion, less useful description than that provided in the mediation hypothesis (Dollard and Miller, 1950, Pp. 106-109; Goss, 1961, Pp. 248-274; Mowrer, 1960, Pp. 29-162; Osgood, 1953, Pp. 401-12, 685-600; and Staats, 1961, Pp. 190-204). In any event, to be useful to research on instruction, the theory will have to lead to some productive independent variables. For a useful discussion of functions of theories of instruction see Bruner (1964b).

Mandler (1962) presents an important paper on association and structure. He discusses the distinction between cognitive and association theories in the use of the term response. From empirical evidence on the effect of over-learning on transfer and from the concept of learning set, he indicates that events which have been given structural and cognitive explanations are amenable, at least in part, to associative explanations. In research on discovery learning, the term "response" has little usefulness because the type or mode of response is often unimportant. If one chooses to use an associational theory to predict the results of studies on learning by discovery, he must remember that the term "response" is deceptive and is narrow in its implication. A term such as "answer" might be more useful (Gagné, 1963).

Gagné, (1963, Pp. 312-317) discusses the nature of problem solving and presents (P. 312) paradigms to describe the hypothetical intervening events which occur in human learning, concept learning, and problem solving. He differentiates (P. 311-312) among the types of learning according to their complexity. "Increasing complexity is seen to reside in not so much what is learned, as in the nature of what happens to be preavailable. . . in order for various types of learning to occur. Thus, verbal paired-associate learning in its pure form occurs when the responses (or response-connections) are already available (cf. Underwood and Schulz, 1960), originally made so presumably, by previous learning... and so on until the most complex form, problem solving is reached, which depends upon the preavailability of capabilities acquired in all other forms of learning". However, Gagné (P. 312) was aware that such descriptions and paradigms do not describe the whole learning situation or even the independent variables.

The measurement of the behavioral results of mediating events is covered in a well-known volume on the measurement of meaning (Osgood, Suci, and Tannenbaum, 1957). However, in this volume one finds most attention to the affective and connotative dimensions of mediating events. Relatively little attention is given to denotative meaning and its transfer.

Comment

Perhaps it is too much to ask that a theory, such as mediation theory, lead to predictions about which independent variables are most likely to produce an effect upon learning by discovery. However, mediation theory will have to describe such events as "verbs" or perhaps even sentences before it will become of definite usefulness to the complicated issues which occur in hierarchically ordered subject matter and in problem solving. At present, a mediator is usually synonomous with a noun or the name of a concept.

When Duncan reviewed the recent research on problem solving (1959) and Schulz (1961) the research on transfer of training, they indicated a need for studies which would try to relate stimulus events as antecedents to behavior as consequents. Duncan writes "Problem solving particularly needs research to determine the simple laws between dimensionalized independent variables and performance" (1959, P. 248). Schulz writes "Until we know what the variables are that cause problem solving to vary in predictable ways, our teaching is less likely to be as effective as it might be. Therefore, it is prerequisite to our success as educators that we discover the laws which describe the functional relations between the various kinds of antecedent variables and later problem solving performance." (1960, P. 62). One feasible way, other than that of dust-bowl empiricism, to isolate those independent variables, which are likely to affect later problem solving performance, is to begin with a theory which calls attention to certain independent variables. At present, no theory is adequate for this purpose.

Independent Variables

Some of the dimensions of the independent variables which occur in learning by discovery have also been studied in research on concept learning and problem solving. To review adequately all these independent variables would require much more time and space than are available. The reviews of problem solving by Duncan (1959) and by Gagné (1959) are recommended. However, several of the important independent variables will be discussed here. The first is the effect of language including variety of verbal stimuli, labeling, verbalization by the experimenter, and verbalization by the subject.

Variety of Stimuli. Most of the research on variety of verbal stimuli has varied the number of examples of problems and the number of repetitions per example. With transfer as a criterion, most of these studies have shown that a variety of problems produces the best performance if each of these problems was learned to at least a moderate degree (Callantine and Warren, 1955; Dashiell, 1924; Crafts, 1927; Lloyd, 1960; Morrisett and Hovland, 1959; Duncan, 1958). When variety of classes of problems (Wittrock and Twelker, 1964), rather than variety in number or repetitions of problems, has been an independent variable the greater variety produced an increased amount of transfer to new problems. These results would imply that it is important for learning by discovery that a variety of problems be presented and practiced. At least this would seem to be justified in some instances.

Language. Perhaps the crux of the learning by discovery issue involves the effects upon transfer of problem solving produced by language. For example, should the experimenter or the teacher express rules and principles in language and present them to the student or should the student derive them himself. Should the student verbalize labels, rules, and explanations or shouldn't he? No doubt the answers to these questions will depend on many variables and will involve higher order interactions. However, there is a wealth of support from the literature on verbal mediation and concept learning to indicate that language is indeed a most powerful independent variable.

The effects of verbal mediation have been shown in conditioning, (Grice and Davis, 1958) paired-associate learning, (Norcross and Spiker, 1958), and concept learning (Berkson and Cantor, 1960; Carey and Goss, 1957) to mention a few. See Cofer (1960), Cofer and Foley, (1942), and Goss, (1961) for further treatment. These studies, and many others not mentioned here, give support to the notion that transfer is affected by verbal mediation and that dissimilar stimuli come to be grouped together because of verbalization or verbal training which associates this dissimilar stimuli with one another.

Language also affects the transpositional behavior of young children (Kuenne, 1947). She found that children who were verbal would show transposition on both far and near stimuli, although the pre-verbal child would not necessarily show verbal transposition to far different stimuli. She found that among those children who could verbalize the principle for solution , either spontaneously or in response to questioning after the experiment, seventy-three per cent transposed on the far test. None of those children who could not verbalize the association between size and success or failure on the choice behavior showed far transposition. However, her study does not demonstrate a cause and effect relationship between verbalization as an antecedent and transposition as the consequent.

Spiker, Gerjuoy and Shepard (1956) found that children who possessed and verbalized the concept "middle-sizedness" learned a relational task more readily than those subjects who did not possess this concept. As in the Kuenne study, the variable was studied by selecting subjects on the basis of their previous learning rather than by experimental manipulation. However, these studies give some evidence that previously acquired verbal concepts influence learning and performance.

More convincing evidence about the effects of language upon learning comes from attempts to train children during the experiment. For example, Cantor (1955) found that five year old children who were trained to name with feminine names two pictures of faces of females could later discriminate two objects that were alike except that each of them possessed one of the pictures of females. This group, called the Relevant Subject group, performed better than did a group trained on irrelevant pictures (pictures of males) or a group that was told simply to attend to the stimuli. Shepard (1956) found an increase in generalization following verbal training which involved learning a common name for the training and test stimuli. Learning the common response for the stimuli resulted in a mediated generalization.

One of the most interesting of these types of studies is one reported by Luria (1961). By describing foreground and background in terms of rainy days (gray) or bright sunshiny days (yellow) he was able to teach children to attend to the background stimulus and to make discriminations on the basis of the color of his background. Without speech stimuli these discriminations were very difficult.

For further studies on the effects of verbal generalization, stimulus pre-training, stimulus pre-differentiation, and verbal labeling see the following studies: Cantor (1955), Dietze (1955), Gagné and Baker, (1950), Ervin, (1960), Jeffrey (1957), Jeffrey and Kaplan, (1957), Robinson, (1955), Rossman and Goss, (1951), Schutz (1962), Spiker, (1956), and Staats, Staats, and Schutz, (1962).

Of special interest is a chapter on labeling by Dollard and Miller (1950, Pp. 281-304) In this chapter they present three ways in which the patient can be taught or can learn new verbal responses. In the first method the patient is allowed to discover for himself verbal novelties. In the second method the experimenter or the therapist strengthens the patient's responses by selective repetition. In the third method the experimenter gives the patient new verbal labels in an effort to change his behavior. They say (P. 301) that method one is to be preferred, at least when it is probable that the patient will hit on the new verbal unit by himself. The primary reason is that when the patient produces a verbal label it will be made in the presence of the correct cues and will not have to be learned to new cues. However, method one does not always produce relevant responses.

Method two is useful when the patient produces a number of different hypotheses and labels. When the patient has an insufficient number of relevant hypotheses or labels, method three should be used. Then it is the therapist who must teach these new verbal labels, and it is the patient who should rehearse them. Although their writing was done in the context far different from that of discovery learning, there are some interesting parallels between these three methods and the role of a teacher who would teach by discovery.

Another type of training which has been shown to affect problem solving, transfer, and concept learning involves the use of overt verbalization by the subject while he is learning or solving problems. One study which is relevant to learning by discovery is by Gagné and Smith (1962). After reviewing Katona (1940), and Haslerud and Meyers (1958), Gagné and Smith studied the effects upon problem solving of two independent variables. They were the S's verbalization during practice and the instructions to find and to state a general principle. There were 28, ninth and tenth grade boys in the study. They were divided randomly into four groups which were composed from all possible combinations of the two, two-factored independent variables (i.e., verbalizing versus non-verbalizing, solution set versus no-solution set). On transfer to new problems, the groups required to verbalize did significantly better than those who were not required to verbalize. This was true both in terms in number of moves and in terms of time. The task they used was the 3-circle task used by Ewert and Lambert (1932), which will be described below. All other differences between pairs of groups were not statistically significant. They also found that the groups who were required to verbalize performed better than the non-verbalizing groups on a test of ability to state verbal principles. They summarize their results (P. 18) as follows: "The results appear to indicate that requiring Ss to verbalize during practice has the effect of making them think of new reasons for their moves, and thus facilitates both the discovery of general principles and their employment in solving successive problems."

This study presents some support for the notion introduced above in the study by Kuenne. In the Gagné and Smith study, there was experimental manipulation whereas some of the earlier studies relied on the pre-experimental learning of the subjects to form their experimental groups.

However, the effect of verbalization by S seems to depend on many variables. The experimental data range from negative effects through no differences to positive effects. Wittrock (1963) found an interaction between MA and response mode. The above median MA kindergarten subjects learned kinetic-molecular theory well whether they said aloud the labels for the concepts or did not say them aloud. However, the below median MA children profited from making overt responses, i.e., saying the labels aloud. For further studies on this variable see Birge, (1941); Jeffrey, (1953); Kendler and Kendler, (1961); Kurtz and Hovland, (1953); Pyles, (1932); and Thomson, (1946).

Instructions. Another category under the sub-heading of Language is instructions. See Gagne (1964). Ewert and Lambert (1932) used as a task the moving in the least possible number of moves cardboard circular disks from one circle to another. The three circles were arranged in a triangular configuration. The cardboard circular disks were graduated in size and the object was to maintain the order of size within the stack and yet to transfer the disks one at a time, from one circle to another circle. One of the groups was given "minimal" instructions about the general rules of the game. A second group was told to try to find a general principle. A third group was given the principle in verbal form while a fourth group was given the principle and a demonstration of how to solve a problem. The groups given the verbally stated principle did significantly better than the groups which were not given the principle.

Maier (1930) studied the role of direction on reasoning and problem solving. His double pendulum problem was solved by eight of the twenty-two subjects on the direction group. Only one of the 62 subjects solved the problem without the added cue ("Observe how easy the solution would be if you could only hang the pendulums from two nails on the ceiling"). Providing additional information here resulted in improving the problem solving success. Saugstad (1955) showed that performance on these problems can be improved if recallability or availability of prerequisite associations is induced.

Luchins (1942), in another well-known study, showed that a general cue "Don't be blind" increased the problem solving of the adult subjects, but not of school children. Here a very general cue changed negative transfer, which was produced by working six problems of one type into positive transfer for problems numbered seven and eight. However, the sentence was not effective with children.

Reed (1946) investigated the effect of instructions on learning and retention of concepts. He found that instructions to learn the meaning of, as well as the name of, a stimulus produced a much higher rate of learning and degree of retention than did a set to learn only the names. The condition which produced the best learning did not involve giving the subjects detailed information about the meaning of the cards. However, the direction which he introduced did increase learning and retention. It seems that a minimal amount of direction improves performance over a situation which does not contain this type of verbal direction. Wittrock, in several experiments, found that with adolescents and with adults a general cue, which contains no information about the subject matter, can still increase the learning of principles. This was true whether the subject matter was principles of Economics (1963 a), Buddhism (1963b), or History, American government, and English (1962).

Underwood and Richardson (1956) studied concept learning as a function of instructions and of dominance level of concepts. Unrestricted instructions (UR) gave the subjects nothing about the nature of the concepts to be learned. They were told only that it would be a good idea to vary their responses from trial to trial. Partially restricted (PR) instructions gave the subjects a class of responses needed to form the concepts. The experimenter probed the subjects about simple ways to describe common objects. Completely restricted (CR) instructions gave the subjects the six correct responses which they were allowed to keep before them and study during the experiment. The results showed that the greater amount of information given the subjects concerning the content or the nature of the concepts to be learned, the more rapid was the acquisition of concepts.

The above studies on the use of language, and particularly those studies on the use of instructions, indicate that problem solving and concept learning can be facilitated by guidance upon discovery. In many instances, quite direct and specific guidance, which specifies the correct concepts, can also facilitate problem solving and concept learning. This is not to say that learning cannot occur incidentally or that it cannot occur without awareness or without instructions (Adams, 1957; Bugelski and Scharlock, 1952; Postman, 1963; Postman and Sassenrath, 1961; Sassenrath, 1962).

Learning Set. Much of the work in learning set is also relevant to the area of learning by discovery; for example, Harlow (1949; and Harlow and Harlow, 1949). By providing a sequence of problems which gradually increase in difficulty and complexity, one can teach animals and children to discover the solution to discrimination problems and to quickly alter their behavior after one "mistake", i.e., to form learning sets. One important implication of the Harlows' work with learning set is that, even without verbal stimuli, by developing a sequence of discrimination problems and by use of successive approximations, sophisticated and complex behavior can be taught. There is a definite need to study the sequence of stimuli and problems which may teach a child to discover. The old induction-deduction variable deserves some attention.

Individual Differences. Bruner, Goodnow, and Austin (1956), in a well known volume on thinking, studied the process of concept attainment, including individual differences in the attainment of conjunctive, disjunctive, and relational concepts. Concept attainment referred (P. 22) to the process of distinguishing members of a class from non-members by finding predictive defining attributes.

When the learner had control over the sequence of stimuli presented to him they identified four "ideal" selection strategies which subjects might use, at least in attaining conjunctive concepts. The strategies were: Simultaneous Scanning, Successive Scanning, Conservative Focussing, and Focus Gambling.

When the learner did not have control over the sequence of instances presented to him, they identified two "ideal" reception strategies, Wholist and Part-Scanning.

Although Harris (1962) has questioned the discriminability of these strategies from one another, Bruner, et. al. (1956) made an important attempt to specify particular ways or strategies of categorizing stimuli. These strategies, or others of their ilk, may be in a learner's repertoire when he attempts to learn by discovery. They must then certainly influence the outcome of experiments.

It is doubtful that experimentation on learning by discovery can proceed fruitfully without first giving much attention to the study of individual differences in cognition, such as those by Bruner and also of Kagan.

Whether a descriptive label such as "Conservative Focussing" is useful or not is not the point. The point is that the individual history of the learner inevitably interacts with experimental treatments. We need to know about his history, and to measure and describe it in ways that are useful to experimentation.

Even IQ, as a subject variable, must be considered in interpreting results of studies on the processes of concept attainment. Osler and Trautman (1961) found that complex stimuli slowed the performances of the superior IQ subjects, but not the "average" subjects, when measured by frequency of attaining criteria and also by number of errors to criterion.

Kendler and Kendler (1959) in a very well known study on reversal and non-reversal shifts, have dramatically indicated the importance of studying individual differences in concept learning and in mediated generalization. With relatively simple stimuli (few obvious dimensions) they found reversal shifts to be made more easily than non-reversal shifts by the older children. Non-reversal shifts were made more easily than reversal shifts for the younger children. Age, or some change which occurs with age, apparently is an important variable.

The field of individual differences has made important contributions to knowledge about cognition. This knowledge should be used, more than it has, to generate hypotheses for experimental research.

Applications to Teaching and Training

Three of the independent variables discussed above--instructions, learning, set, and individual difference are combined by Gagné (1962) and applied to the teaching of complex subject matter (Gagné, Maier, Garstens, and Paradise, 1962; and Gagné and Paradise, 1961).

Gagné (1962) reasoned that for the learner to perform on the dependent variable, certain knowledge is prerequisite and certain instructions from the experimenter are necessary. The term "knowledge" refers to information, ideas, etc., that are particular to a certain subject matter. The term "instructions" pertains to sentences which communicate something to the learner, when that something is usually not particular to a certain subject matter. He reasons that instructions perform at least four functions. First, they help the learner to identify the required terminal performance. Second, they identify elements of the stimulus situation which are important. Third, they enhance recallability of learning sets. Fourth, they guide thinking. The term learning sets applies to a subordinate class of tasks which are necessary for the learner to be successful on the dependent variable, provided he is given only instructions. These learning sets are hierarchically arranged such that the lowest members of the hierarchy must all be present before more advance members of the hierarchy can be performed. The lowest members mediate positive transfer to the higher levels. If one of the lower members cannot be recalled, transfer from one learning set to another would be zero. If the lower members can be recalled, transfer will range up to 100 per cent. Although one can question what Gagné means by one learning set being prerequisite to another, or being simpler than another, the results he obtains with his analysis are impressive.

For example, in the study by Gagné and Paradise (1961), they asked the questions "What would the individual have to be able to know how to do in order to be able to perform this (new) task, being given only instructions?" (Pp. 16-17). They studied the effects of mental abilities factors and learning sets upon the solving of linear algebraic equations. Among the important findings were those which indicated that subordinate learning sets mediate positive transfer to other members in the hierarchy. The proportion of transfer ranged from .91 to 1.00. They also predicted and found that while the correlation of relevant basic abilities with rates of attainment of learning sets progressively decreased at higher levels of the hierarchy, the correlation of relevant basic abilities with achievement of learning sets increased at these higher levels. The correlation between rate of attainment and relevant basic abilities should decrease, according to Gagné and Paradise, because as one proceeds up the hierarchy, transfer depends increasingly upon the immediately subordinate learning sets or upon specific knowledge. The correlation between basic abilities and achievement of relevant learning sets should increase because, since the learning program is not perfect, high and low ability students will become more differentiated. This increase in the correlation indicates the ineffectiveness of the learning program.

Although again one could give other interpretations to these data and predictions, the work of Gagné and his associates represents an excellent model for future research on learning by discovery and closely related areas. By taking complicated and hierarchically organized subject matter and by analyzing it into its prerequisites and components he has been able to produce impressive results on learning and transfer tests. His paper on the acquisition of knowledge (Gagné, 1962) must certainly be considered required reading for anyone who is seriously interested in the study of learning by discovery and the programing of of complicated subject matter. Gagné's work also indicates that learning by discovery and programing are not incompatible with each other.

Whether one turns to the dependent variables, the intervening variables, the theory, or the independent variables, he finds prominently displayed the work of Gagné and associates. This work is accumulating into an important impact upon the teaching of hierarchically ordered subject matter, problem solving, and transfer.

In contrast to the negative results obtained by Suchman and in the studies summarized by Flavell (1963), several studies report positive results in their attempts to improve problem solving, etc. Crutchfield and Covington (1963) report that within a three week period of work on a special program, 35 per cent of 98, fifth and sixth grade children were taught to solve problems, compared with a matched control sample in which only thirteen per cent were able, without instruction, to solve the problems. Their attempt was to train for a generalized problem solving skill and the posttest consisted of problems which were considerably different from those problems present during training. The training program was a complicated and many dimensional one. According to the authors (P. 4) the program was designed to teach a student to define a problem, to generate his own ideas about solving problems, and to give him immediate and frequent feedback on the questions and ideas which could direct and stimulate his thinking. Finally, the student "participated" with a pair of curious and imaginative children who acted as models to be emulated. Unfortunately, very little information is given about the control and statistical analysis of the results. However, on this type of dependent variable (transfer of problem solving ability), the difference between the control group and the experimental group is impressive. If we can assume for a moment that Crutchfield and Covington have produced a real effect on these dependent variables, it would be important that a thoroughgoing analysis of their treatments be undertaken. An analysis such as the one by Della-Piana and Eldredge on the work of Gagné, as summarized above, should be undertaken. From Crutchfield and Covington's brief summary of their program it seems that the child is given opportunity to discover solutions for himself, but only within the context of a highly organized sequence of problems presented contiguously with considerable verbal direction and cueing from the experimenter. The use of the identification models to teach problem solving is a unique approach.

Stolurow and Bergum (1957) tested the effects of different methods of training upon troubleshooting. The model they presented is one which may have usefulness in discovery learning. They analyzed the symptom-cause and the cause-symptom relationships into their stimulus and response components. They described response sharing, that is, where one stimulus is associated with more than one response, and stimulus sharing, where several stimuli are associated with one response. Last, they described stimulus-response sharing, or many stimuli to many responses, where several stimuli are each associated with each of several responses. They argued that before one can learn new associations, such as symptom cause relationships, he might have to engage in "stimulus learning" or "response learning". Stimulus learning involves differentiating the occasion for one rather than another response. The response learning involved the acquisition of the response repertoire.

By analyzing the complex problem of troubleshooting into its stimulus and response learning components, and by hypothesizing that learning would be more or less difficult in relation to the associations in the learner's repertoire, they predicted and found an interaction between the learner's previous experience with learning style and direction of association and the conditions under which he would acquire generalized habits of learning best during the experiment. This type of careful analysis of stimulus and response factors as well as the analysis of the learner's history, is greatly needed on studies of learning by discovery. However, as discussed earlier, in discovery learning one probably cannot think of particular responses. Instead classes of responses or answers is probably a more useful term because the particular overt form of the response may not be crucial.

Jensen (1964) presents a cogent and detailed argument for attempting verbal training and manipulation of socially deprived youngsters. One point he makes has been made before by Fowler (1962) and by Hunt (1961). It is that the effects of the environment upon learning are scarcely known because it has not been extended or varied greatly enough. Jensen argues for using principles from verbal learning, including mediated generalization, semantic generalization, transposition, paired-associate, and serial learning to prepare training materials for socially deprived youngsters. He also presents (Pp. 124-126) an index to measure the degree of the development of the subjects' ability to mediate in relation to his basic learning score. The ratio is a paired-associate score over serial learning score. Because of his analysis and of the implications he draws for preparing training programs, his monograph is highly recommended for anyone who is serious about the construction of materials which may use the learning by discovery technique.

The importance of the learner's history in determining the outcome of experiments has been shown with nonsense syllables (Underwood, 1957) and with complex subject matter (e.g., Ausubel, 1960; Ausubel and Blake, 1958). Especially when the material is similar or identical to that used in schools, studies on proactive inhibition are important for their implications about discovery learning. One reason is that a problem exists when proactive inhibition occurs. The variables which can be used to reduce proactive inhibition or better yet to obtain proactive facilitation may be important ones to employ in studies on learning by discovery. For example, instructions are often useful to reduce proactive inhibition. Instructions may not be an important variable when materials are designed with careful regard for the past history of the subject, i.e., when proactive inhibition should not occur.

Comment

Future research on learning by discovery should be built upon research such as that discussed above and labeled as related studies. These related studies have analyzed and experimented with the dependent variables, the hypothetical intervening processes, and many of the independent variables. Verbalization of generalizations and rules by S seems to produce learning and transfer in many of the studies on the effects of language. Perhaps some of the writers on discovery learning have too quickly rejected or disparaged the use of verbal stimuli in discovery learning. It would be appropriate to try to design sequences of verbal and non-verbal stimuli whose aim was either to teach "how to discover" or to teach concepts. It may be that these two ends can be achieved by one sequence.

In any event, the research on concept learning, problem solving and transfer is weighted with ideas and hypotheses which should be transferred to the study of learning by discovery. Several people, e.g., Gagné, Glaser, and Stolurow, are currently extending to training and to complex teaching situations some of these ideas. Apparently they are having definite success, although no one would argue that these complex situations involve only those variables studied so far in problem solving research. In fact, one should be prepared to expect negative transfer, at least occasionally, when he tries to apply to complex verbal learning the results of relatively simple, non-verbal laboratory studies.

VI. Discussion

A purpose of the Discussion is to consider on the basis of the writings summarized above, the issues about the hypothesis and the term "discovery" which were presented in the Introduction. A more important purpose for the discussion is to raise some issues which may be more useful than those which are in the Introduction or are currently popular among schoolmen and researchers.

Uses of the term Discovery

Definitions of complex terms are necessarily oversimplifications. The term discovery is used in many different ways and some of those ways should be made explicit. The result may not be a useful definition, but it may lead to a clearer understanding of the term and perhaps to the development of a more useful term and hypothesis for future research.

Discovery is used to describe at least the following elements in situations: First, when a teacher or researcher uses non-verbal stimuli rather than verbal stimuli, discovery is sometimes used to describe the situation. However, that is too much of an oversimplification. When rules or generalizations, rather than a variety of specific instances or problems, are verbalized or described by a teacher or researcher, the situation is often labeled a "discovery" treatment. When labels for concepts are not given by the teacher, the situation is also sometimes labeled "discovery". There is at least one exception to these last two statements. Sometimes the verbalization of very general or vague cues rather than specific ones, is also labeled a discovery procedure. It seems that discovery may apply so long as a fairly specific rule or generalization is not mentioned by a teacher. The use of explanations of rules or generalizations is confounded in the literature. Usually giving an explanation of a generalization tends to detract from the discovery potential of a situation.

It might be well to ask here what is the student supposed to discover--a rule or a set of specific but related answers? If discovery were accurately indexed in terms of student behavior or knowledge, it would be easier to estimate those situations which would preclude his producing that behavior on his own, and without certain types of direction from a teacher.

The second element of a situation which is labeled "discovery" involves learner control of the rate and sequence of stimuli which are presented to him. For some reason this stiuation is not often studied in the recent research.

The third element pertains to a dependent variable, to types of student response; e.g., a student solving problems, or working in a laboratory, and making overt responses. There is supposed to be a "sub-verbal awareness", usually indexed by overt excitement and increased acitivity. (Hendrix, 1961). Transfer, savings,and retention of concepts and especially of problem solving abilities apparently are considered important dependent variables. Ability to use a certain method to verbalize rules, conclusions, etc., is sometimes an index of learning by discovery. Another important response variable is affectivity. If the student "discovers;" he is supposed to display positive emotions, increased interest in the subject matter, and in solving problems.

Another element in the event is the student's history with the subject matter or closely related area. Discovery learning usually is confined to hierarchically arranged subject matter in which the learner has considerable background; therefore, with instructions (as Gagné uses the term), he has a fairly high probability of deriving by himself correct answers and generalizations. Probably it is the intersect of these stimulus and response variables which comprise the situations to which the label "discovery" is applied.

However, the above analysis of the term leaves much of the meaning and excitement out of it. It is a hypothetical, intervening cognitive event which is implied by the term. Certainly Hendrix was proceeding in an important way when she tried to index discovery by facial and other emotional processes rather than indexing it by describing teacher behavior or by describing student answers to a transfer test. If it is useful as an intervening event, we should try to find these types of indices which will separate it from the transfer or the treatment measures.

Current use of the term discovery is interesting more by what is omitted than for what is denoted or connoted. For example, there is little use today of measures of originality or creativity as dependent variables.

In several ways, earlier excess meaning has been sloughed off in recent years. Induction-deduction is now a separate variable, since the learner can "discover" from either very general or very specific cues presented before the other. Induction-deduction pertains to the order in which general and more specific cues are jointly presented.

The rote-meaningful distinction has also disappeared largely as a description of treatments. It carried too much surplus meaning. The early field-theory versus Thorndike controversy involved far more than discovery. In fact, one could argue that Thorndike's treatments which specified correct answers without explanations left much room for student discovery. Field-theory, which sometimes injected explanations and verbalizations of generalizations, often left reduced opportunity to discover these verbalizations.

Discovery has not often been used to describe the teachers' behavior. It may be that one reason why the "new" curriculum projects are productive and exciting is that they require the teachers and writers to become personally involved in the preparation and try out of materials. The writer receives feedback from the students' responses. The teacher builds on the students' history and upon his own history of solving pedagogical problems. He is required to discover those conditions in which the students learn and transfer best. It may be the teachers and writers who are learning by discovery and who are liking it.

If we can generalize from Hendrix research, perhaps it would be best for the researchers on discovery learning to suppress their desire to verbalize their own sub-verbal, but little understood, awareness of the factors which cause their results.

One might also ask why "discovery" has not been applied to much of programed instruction. In fact, programming and discovery are sometimes seen as antithetical to each although both often involve student derivation of generalizations, problem solving, active responses, and student determination of rate, if not of sequence of material. It would seem that with the obvious exception of student determination of sequence of material, programmed instruction and discovery learning can have much in common.

Uses for the term and for the hypothesis of "discovery"

More important than the current trends in uses of the term are the uses for the term and for the hypothesis. Are students simply inducing "discoveries" from data when they solve problems? Or are they imposing or applying previously learned generalizations and even biases upon these data? Is learning by invention a term equally as useful or obstructive as is the term discovery?

Before trying to answer such a hypothetical question one might ask another question. Useful for what purposes: to describe an intervening event, to hypothesize about stimulus-response relationships, to direct research to productive stimulus parameters, and to teach subject matter?

As a description of an intervening event, discovery must compete with terms such as "mediating stimuli and responses", "invention", "motivation", "orienting response", "concept", and "curiosity." Which terms are most useful?

As an hypothesis about stimulus-response relationships, discovery seems to have been too useful. It may have directed many people to too few stimulus variables. They may have been distracted from other important variables such as the transfer effects of verbal direction by a teacher. In strong defense of the discovery hypothesis is the fact that few learning theories are actually theories which indicate stimulus conditions that are likely to enhance acquisition. The discovery hypothesis led many people to study the effects of practicing problem solving. What other important variables are there? Does the discovery hypothesis indicate any others?

What relationship has a theory of teaching or instruction to a theory of learning? If the discovery hypothesis is useful for building a theory of instruction, it should indicate at least part of the relationships that exist between teachers, books, programs, etc., and response variables. Does the discovery hypothesis indicate or depreciate these relationships? Should a discovery treatment be considered only as a control treatment against which to compare more verbal and directed sequences?

As an objective for teaching, the ability to discover is important in its own right. It is probably important to separate discovery as an objective from discovery as a way to teach. It is probably also important to remember that simple practice at the terminal behavior of discovering may not be a most effective or efficient way to teach a child to discover.

How can we achieve discovery as an end? There is not much doubt that we need research on the teaching of discovery. Do we need a hypothesis that indicates independent variables (other than that of practice) that will probably produce ability to discover? If we do, does the discovery hypothesis indicate any of them?

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